A REPORT ON THE HARTSFIELD INCINERATOR STUDY

This report (SW-30ts.of) was written by

Leland E. Daniels

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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Bureau of Solid Waste Management
1970

FOREWORD

Incineration is an important method of solid waste processing in the United States, and although over 300 incinerators are in operation, little information on the performance of these units is available. It is therefore not surprising that the effects of incineration on the environment are little understood and frequently ignored.

An incinerator discharges effluents into the environment in three states: solid, liquid, and gaseous. The sources of these effluents are the processes of combustion, gas cleaning, and residue quenching. Any determination of the pollution contribution to the environment by incineration must be concerned with all these effluents.

The Bureau of Solid Waste Management, through the Division of Technical Operations, has initiated a testing program to characterize the performance of incinerators of different designs and configurations. The primary objectives of this program are to produce basic information that identifies the results of the incineration process and to develop reliable sampling methodology.

During the studies it is considered necessary to make a complete analysis of all features that affect the operation of the facility as well as those that influence its potential for environmental pollution. The operation of the facility is not altered in any way unless specific study objectives dictate a change. Therefore, no special effort is made to operate the facility at its design capacity; rather, it is tested at its "operating" capacity.

Reports from each study in this program will be prepared primarily for use by the management of the facility, although they will be available upon request to other interested technical personnel. Each report will contain only the data obtained during one individual study. Data comparisons with other studies will not be made in individual study reports.

In October 1968, Mr. M. DeVon Bogue, Regional Program Representative, Region IV, Bureau of Solid Waste Management, arranged with Mr. Joseph E. Morgan, Superintendent of the William B. Hartsfield Incinerator, for the Bureau of Solid Waste Management to test this rotary kiln incinerator. The purpose of the test was to develop basic information pertaining to the operation of the incinerator and its potential impact on the surrounding environment. The study was conducted during the week of December 9 to 13, 1968.

--RICHARD D. VAUGHAN, *Director*
Bureau of Solid Waste Management

C O N T E N T S

SUMMARY 1

Solid Waste 1

Residue 2

Plant Efficiency 2

Process Waters 2

Burning Rate 4

Particulate Emissions 4

Economic Analyses 4

Bacteriological Analyses 5

FACILITY DESCRIPTION 7

Solid Waste Handling 7

Combustion Unit 10

Residue Disposal 14

Metal Salvage 14

Air Pollution Control 14

Instrumentation 15

TESTING PROCEDURES 17

Solid Waste 19

Residue 20

Particulate Emissions 21

Stack Gases 22
Process Waters 23
Cost Analyses 23
Bacteriological Analyses 23
RESULTS 27
Solid Waste 27
Residue 29
Plant Efficiency 32
Process Waters 33
Instrument Readings 33
Burning Rate 36
Particulate Emissions 36
Cost Analyses 37
Bacteriological Analyses 42
REFERENCES 48
ACKNOWLEDGMENTS 50
APPENDICES
A Example Calculations for the Ash, Volatile, and Heat Content of the Solid Waste 51
B Example Calculations for the Ash, Volatile, and Heat Content of the Residue 55
C Plant Efficiency Calculations 59
TABLES
1 Design Characteristics per Combustion Unit 12
2 Solid Waste Characteristics Assumed for Furnace Design . . 13

3 Design Combustion Temperatures 13
4 Sampling Schedule 17
5 Solid Waste Composition 28
6 Proximate Analyses of Solid Waste 29
7 Ultimate Analyses of Solid Waste 29
8 Residue Composition 30
9 Proximate Analyses of Residue 31
10 Ultimate Analyses of Residue 31
11 Plant Efficiency 32
12 Average Chemical Characteristics of Wastewater 34
13 Average Solids Concentration of Wastewater 35
14 Stack Test Conditions 37
15 Summary of Particulate Emissions 38
16 Annual Cost Analyses 39
17 Capital Cost 40
18 Cost of Repairs and Maintenance 41
19 Allocations for Repairs and Maintenance 42
20 Operating Cost by Cost Centers 43
21 Projected Annual Cost at Design Capacity 44
22 Bacteriological Data 45
23 Coliform Data 46
A-1 Proximate Analyses of the Combustible Portion of the Solid Waste Samples 51
A-2 Conversion of the Combustible and Noncombustible Data to a Dry Basis 52

B-1 Proximate Analyses of the Unburned Combustibles and Fines 55

B-2 Conversion of the Residue Data to a Dry Basis 56

FIGURES

1 Schematic of the Hartsfield Incinerator 8

2 Hartsfield Incinerator Plant Site 9

3 Flow Diagram of the Hartsfield Incinerator 18

A REPORT ON THE HARTSFIELD INCINERATOR STUDY

SUMMARY

The William B. Hartsfield Incinerator is a rotary kiln incinerator with two identical combustion units, each having a total design capacity of 250 tons per 24 hr. Inclined reciprocating grates are used in the drying and ignition chambers. Further combustion is achieved in the kiln and mixing chamber. The combustion products from each furnace pass through separate water scrubbers and are discharged into the atmosphere through a common stack. The residue drops from the kiln into the quench tank where a drag conveyor removes the residue and discharges it into a residue truck for removal to a disposal site. Wastewater from the scrubber and quench tank flows through a grit chamber prior to its final disposal in a watercourse.

Solid Waste

The principal portion of the combustibles was composed of 58.7 percent paper products and 12.2 percent food wastes. The major portion of the noncombustibles was composed of 10.3 percent glass and ceramics, and 8.6 percent metals. The density ranged from 155 to 265 lb per cu yd and averaged 200 lb per cu yd. During the study period, the waste received by the plant had an average moisture content of 20.2 percent, a volatile content of 70.1 percent (dry basis), an ash content of 29.9 percent (dry basis), and a heat content of 5,030 Btu per lb as received.

Residue

The fines averaged 74.5 percent. This is attributed to the size reduction of the residue as a result of the tumbling action occurring in the rotary kiln. The unburned combustible content averaged 0.1 percent, the metals 21.4 percent, and the glass and rocks 4.0 percent. The density of the residue on a wet basis ranged from 1,365 to 1,590 lb per cu yd and averaged 1,485 lb per cu yd.

The residue had an average moisture content of 21.8 percent, a volatile content of 3.0 percent (dry basis), an ash content of 97.0 percent (dry basis), and a heat content of 520 Btu per lb (dry basis).

Plant Efficiency

The plant achieved a weight reduction of approximately 63 percent, a volatile reduction of approximately 98 percent, a volume reduction of approximately 95 percent, and released approximately 97 percent of the available heat.

Process Waters

During the study the process wastewaters were not measured quantitatively. However, past records showed that the plant consumption averaged 910,500 gal per day or 2,370 gal per ton of solid waste processed.

The scrubber water was acidic (pH varied from 2.5 to 3.0) and the temperature was 149 F. The alkalinity was zero, the chloride content was 295 mg per liter, the hardness was 260 mg per liter, and the phosphate content was 12.6 mg per liter. The total solids concentration was 835 mg per liter of which 10.7 percent was suspended solids and 89.3 percent was dissolved solids.

After the scrubber water was added to the quench tank and the quenched residue was removed, this mixture of scrubber and quench waters was still acidic (pH varied from 3.9 to 7.0) and had a temperature of 119 F. The hardness and sulfate concentrations remained nearly the same, but the alkalinity increased to 235 mg per liter, the chloride concentration decreased to 205 mg per liter, and the phosphate concentration increased to 20.9 mg per liter. The quench water contained 1,495 mg per liter of total solids, of which 60 percent was suspended solids and 40 percent was dissolved solids.

After flowing through the grit chamber, the plant effluent remained acidic (pH varied from 4.5 to 6.9) and had a temperature of 112 F. The chloride, hardness, and sulfate concentrations remained nearly the same, but the alkalinity decreased to 105 mg per liter and the phosphate concentration decreased to 4.9 mg per liter. The total solids concentration was 655 mg per liter, of which 13.0 percent was suspended and 87.0 percent was dissolved. The grit chamber reduced the total solids concentration approximately 55 percent by removing 90 percent of the suspended solids.

Burning Rate

The burning rate was 330 tons per 24 hr, and the plant was operating at 66 percent of its design capacity. This reduced burning rate was caused by insufficient quantities of solid waste, and therefore both furnaces were not operated continuously. However, during the stack tests both furnaces were operated at an average burning rate of 660 tons per 24 hr. Thus the furnaces were operated at 130 percent of design capacity during the stack tests.

Particulate Emissions

The Orsat analyses averaged 5.0 percent carbon dioxide, 14.5 percent oxygen, and 80.5 percent nitrogen. The excess air averaged 220 percent. The particulate emissions averaged 0.73 gr per standard cubic foot (scf) corrected to 12 percent carbon dioxide, 1.19 lb per 1,000 lb of dry flue gas corrected to 50 percent excess air, 238 lb per hr, and 17.2 lb per ton of waste charged.

Economic Analyses

The capital cost of the plant was approximately $3,300,000. Of this amount, one-third was spent on the building and two-thirds on the equipment.

From the analyses of the costs from the previous fiscal year, the operating cost was 67.3 percent of the total annual cost, and the financing and ownership costs were 32.7 percent. The direct labor was

29.9 percent of the total cost. Excluding the operating cost and the revenue received from the metal salvage operation and private haulers, the annual cost was $6.69 per ton of solid waste processed.

When the operating cost is based upon cost centers, 34.1 percent was spent in receiving, 31.4 percent was spent in volume reduction, and 34.5 percent was spent in effluent treatment.

Bacteriological Analyses

The solid waste averaged 54×10^6 bacteria per gram and the residue averaged 55 per gram. Thus the average total bacteria count was reduced by a magnitude of 1 million. Aerobic spores were reduced by a magnitude of 600 and anaerobic spores by a magnitude of only 150.

Relatively high densities of coliforms and fecal coliforms were isolated from the solid waste, 13×10^6 per gram and 0.56×10^6 per gram, respectively. However, coliforms were not recovered from the residue, quench water, stack gas, and fly ash samples and salmonella were not isolated from any sample.

FACILITY DESCRIPTION

The William B. Hartsfield Incinerator is one of the two incinerators serving the Greater Atlanta area and the northern portion of Fulton County, Georgia. The facility is located on 11 acres of land northwest of Atlanta in an industrially zoned area.

The plant is of rotary kiln design with a design capacity of 500 tons per 24 hr. It was designed by International Incinerator, Inc.* and completed in 1963. The plant has two continuous-feed furnaces with a common stack. Each combustion unit consists of three sections of reciprocating grates, a rotary kiln, a gas-mixing chamber, and a water scrubber (Figure 1). The plant also has a metal salvage operation and a small unit for burning pathological wastes (Figure 2). The plant's overall architectural design and landscaping present a pleasing visual appearance.

Solid Waste Handling

Fifty employees operate the incinerator during the 24-hr, 5-day workweek that begins at 7 am Monday and ends at 7 pm Saturday. Solid waste is weighed as it enters the plant and is accepted throughout the workweek from commercial, industrial, and municipal sources.

*Mention of a company or product name does not constitute endorsement by the U.S. Department of Health, Education, and Welfare.

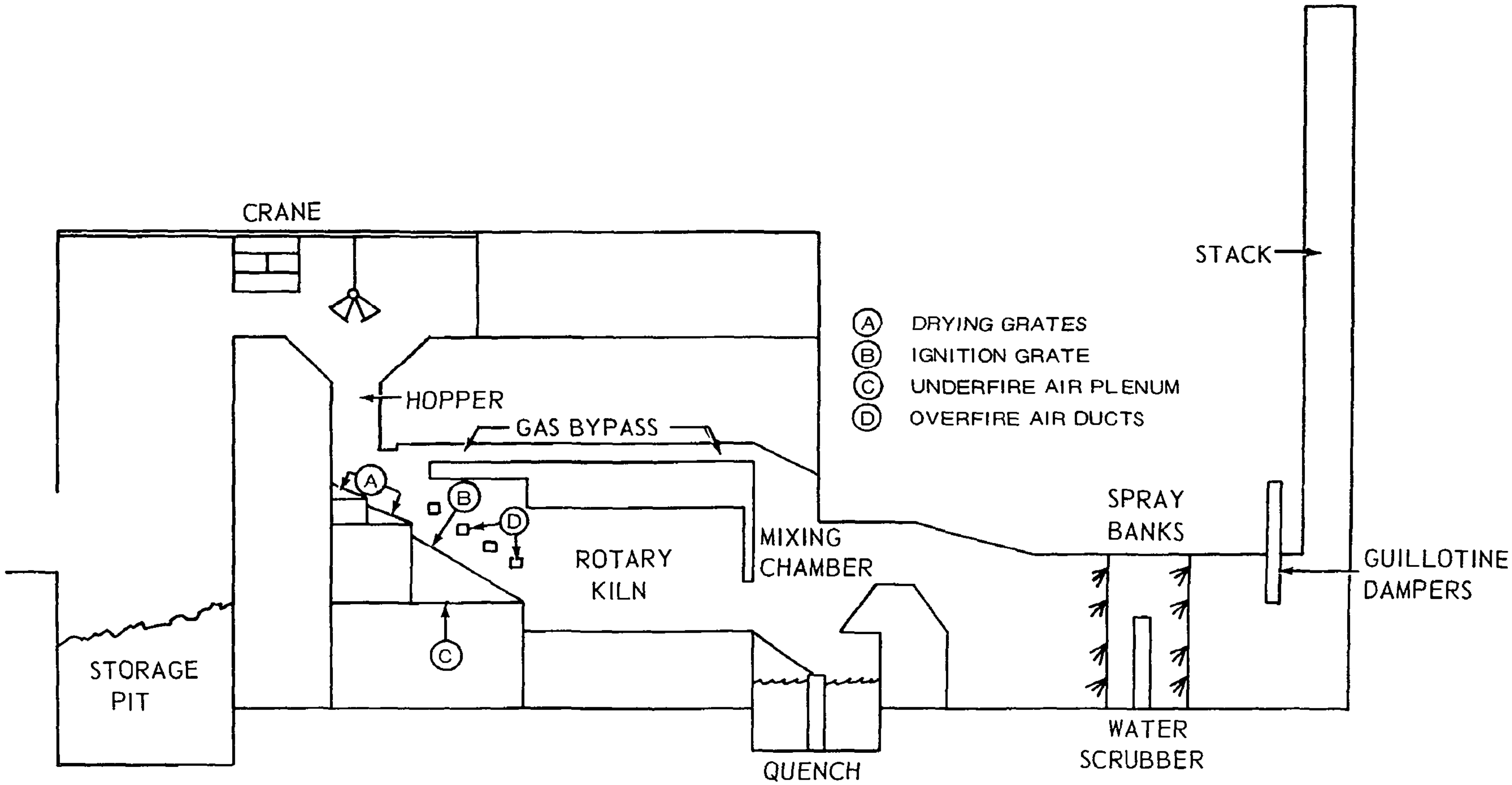
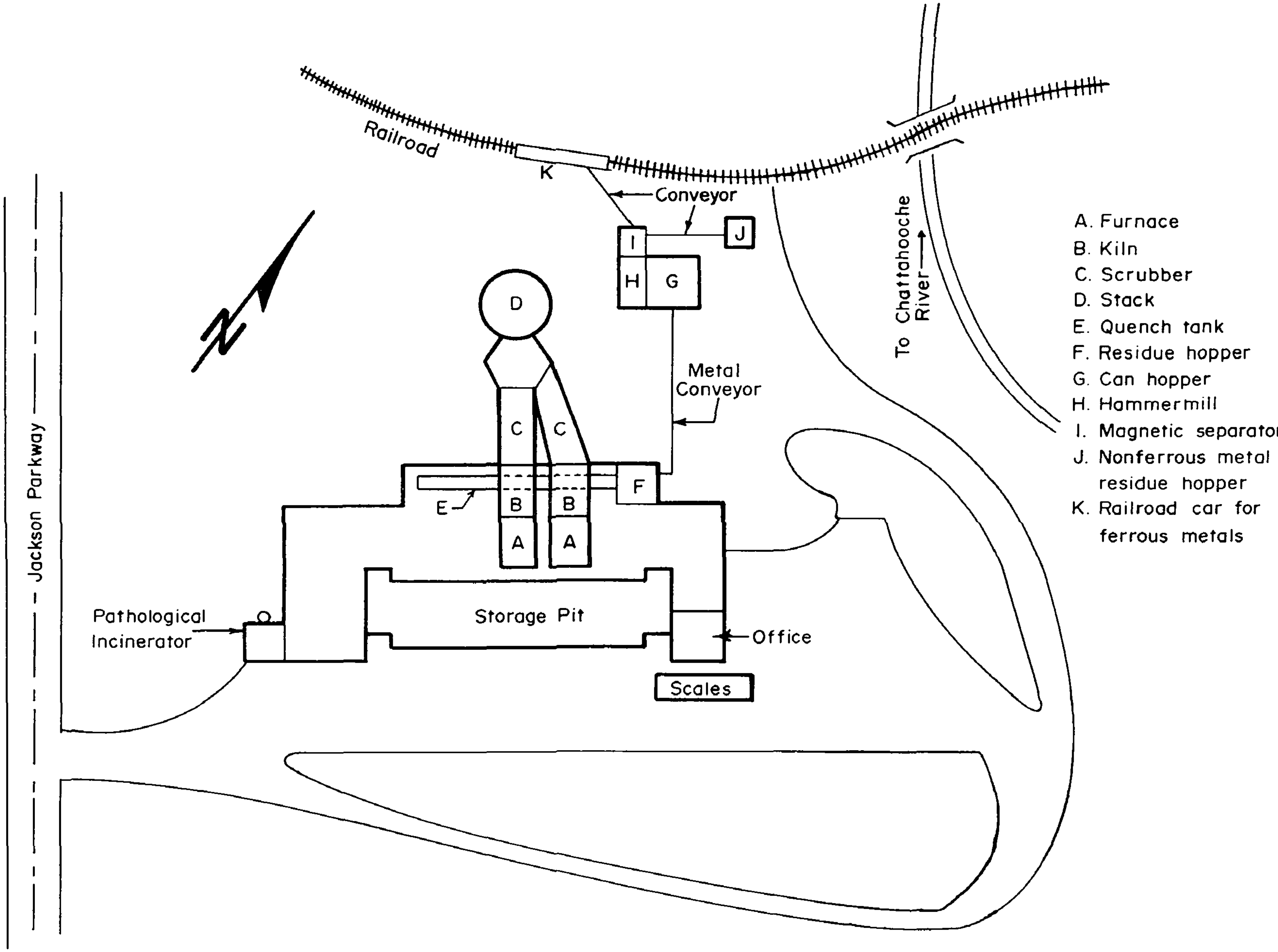


Figure 1. Schematic of the Hartsfield Incinerator.


Railroad
K
Conveyor
I
J
H
G
D
C
C
Metal Conveyor
E
B
B
A
A
F
Storage Pit
Pathological Incinerator
Office
Scales
Jackson Parkway
To Chattahooche River
A. Furnace
B. Kiln
C. Scrubber
D. Stack
E. Quench tank
F. Residue hopper
G. Can hopper
H. Hammermill
I. Magnetic separator
J. Nonferrous metal residue hopper
K. Railroad car for ferrous metals

Trucks from commercial and industrial sources are issued dumping permits. Initially, each truck is weighed several times, both loaded and unloaded, to obtain the average net weight of a truckload of waste. The average net weight is then multiplied by the number of times the truck delivers wastes to the incinerator as a means of maintaining a weight record. Fees for dumping by these commercial and industrial trucks are assessed by the weight of waste dumped. These trucks are periodically reweighed to maintain and improve the average net weight.

Municipal trucks are weighed continuously to maintain weight records. A 50-ton Fairbanks-Morse semiautomatic scale located at the front of the building is used to weigh the trucks.

The storage pit is approximately 27 ft deep, 30 ft wide, and 170 ft long, and has a capacity of 5,150 cu yd when filled to the level of the tipping floor. Two P&H 5-ton-capacity cranes with 3-cu yd buckets are used to charge the furnaces. The enclosed cab is mounted on the crane and contains air-conditioning and heating systems.

Water sprays and ventilators are available for controlling air-borne dust generated within the storage pit during dumping. Eight trucks can be accommodated at one time in the open tipping area. The charging floor and tipping floor are continuously cleared of spilled waste by the operating staff.

Combustion Unit

Solid waste is fed to the furnaces through hoppers that have a cross section of 4 1/2 by 8 ft and a depth of 10 ft. The hoppers are lined with heavy-duty refractories.

Each furnace was designed to burn 250 tons of solid waste per 24 hr. Each contains two sections of inclined reciprocating drying grates and one section of inclined reciprocating ignition grates. Siftings that fall through the drying grates are moved by an auger to the ignition grates. Siftings from the ignition grates are also moved by an auger to the quench tank. Suspended walls and super-duty refractories were used to construct the furnace. Provisions were made for future construction of a third furnace identical to the original two.

Each furnace has a forced-draft fan rated at 25,000 cfm at 10 in. of water static pressure. This fan supplies both the overfire and underfire air to the ignition grates. The overfire air enters the furnace over the ignition grates through ducts in the wall. The underfire air enters the furnace through the ignition grates from a plenum chamber below the grates. Manually operated dampers control the distribution of the air. Past operation has relied primarily on underfire air with occasional use of overfire air.

Approximately 35 percent of the hot gases bypass the kiln by flowing from the ignition chamber over the incoming waste. The gases then flow through a bypass duct located above the drying grate to the mixing chamber where they combine with the remaining combustion gases (Figure 1).

The design specifications (Table 1) were determined from the required design capacity, the assumed solid waste characteristics (Table 2), and the combustion temperatures (Table 3).

TABLE 1

DESIGN CHARACTERISTICS PER COMBUSTION UNIT

Component	Specifications	
Drying grates	Number	2
	Total area	114 sq ft
	Feed rate	min. 1.8 tons/hr; max. 17.5 tons/hr
	Stroke	4.5 in.
	Total volume above grates	1,150 cu ft
	Drop distance between sections . .	2 ft 4 in.
Ignition grate	Number	1
	Total area	110 sq ft
	Feed rate	Min. 1.8 tons/hr; max. 17.5 tons/hr
	Stroke	4.5 in.
	Total volume above grate	1,220 cu ft
	Drop distance to kiln	4 ft 4 in.
Kiln	Internal diameter . .	10 ft 8 in.
	Length	23 ft 1 in.
	Surface area	780 sq ft
	Volume	2,100 cu ft
	Speed	Min. 0.014 rpm; max. 0.232 rpm
	Refractory	Initial 15 ft--super duty; last 8 ft--70% alumina
Mixing chamber	Volume (to first spray bank)	3,000 cu ft
	Gas velocity	33 ft per sec @ 1,800 F
Gas bypass duct	Volume	780 cu ft
Settling chamber	Volume	2,000 cu ft
	Gas velocity	33 ft per sec @ 600 F
Temperature reduction chamber	Volume	2,200 cu ft

TABLE 2

SOLID WASTE CHARACTERISTICS ASSUMED FOR FURNACE DESIGN

Characteristic	Value
Moisture	50-20%
Combustibles	35-65%
Noncombustibles	15%
Heating value	2,600-5,000 Btu/lb

TABLE 3

DESIGN COMBUSTION TEMPERATURES

Heat content in fuel (Btu/lb)	Temperature (F)	
	Before settling chamber	After settling chamber
2,600	1,450	580-620
5,000	2,000	580-620

The common stack provides the natural draft required to remove the combustion products from both furnaces. The stack is 200 ft high, has a diameter of 16 2/3 ft at the sampling ports, and is lined with intermediate duty fireclay brick. Guillotine dampers located after each scrubber are used to control the natural draft to the individual furnaces.

Residue Disposal

After passing through the kiln, the residue falls into one of the two available quench tanks. A gate directs the residue into the desired tank. A drag conveyor removes the residue from the quench tank to the residue hopper. Six trucks, each with a capacity of 8 yd, are used to haul the residue to a disposal site located 4 miles from the incinerator, where the residue is spread as cover material. The residue is not normally weighed as it leaves the plant.

Metal Salvage

Metal is continuously separated from the residue at the end of the drag conveyor by processing the residue through a perforated rotating drum. The fine materials (ashes, glass, rock, etc.) fall through the perforations into a hopper, and the largest pieces, primarily metal, pass through the drum and to the metal salvage operation. After the metal is washed with water taken from the quench tank, it is conveyed to a storage hopper. The metal is passed through a hammermill for size reduction, and a magnetic separator removes the ferrous metals which are then conveyed to a railroad car. The nonferrous metals drop into a grit chamber where they are removed by a drag conveyor for disposal at the landfill.

Air Pollution Control

A water scrubber containing two banks of sprays with a partial baffle wall between them is used to reduce the fly ash emissions. Each spray bank contains 11 vertical water lines spaced across the width of the scrubber. The first bank contains five 1/8-in. holes per line and the rear bank contains four 1/8-in. holes per line. Thus the water scrubber contains 99 water sprays that spray downward at a 45° angle. A layer of water is impounded on the floor of the scrubber by a standpipe. Overflow through this standpipe is continuously discharged into the quench tank. Every 4 hr the fly ash entrained in this pool of water is sluiced to the quench tank.

Instrumentation

An instrument panel is located on the main furnace floor between the two furnaces. Instruments included are draft gauges, temperature recorders, grate speed controls, and kiln speed controls. The instrument readings are recorded hourly in a daily operation log. The total draft supplied by the forced-draft fan, the draft above the ignition grates, the draft in the mixing chamber, the draft in the scrubber, and the natural draft provided by the stack are monitored.

Temperatures are recorded from thermocouples located above the drying grates, above the ignition grate, in the mixing chamber, and at the base of the stack.

TESTING PROCEDURES

This section discusses the methods used to collect and analyze the following samples: (1) solid waste, (2) residue, (3) stack particulate emissions, (4) stack gases, and (5) process water. The sample preparation for the bacteriological analysis is also described. The sampling locations (Figure 3) of the solid, liquid, and gaseous products from the incinerator were based upon their flow systems and ease of sampling.

A field study of the Hartsfield Incinerator was conducted from December 9 to 11, 1968, to determine the characteristics of its operation. Samples were collected according to the schedule shown in Table 4.

TABLE 4

SAMPLING SCHEDULE

Source	Samples		
	Monday (12-9-68)	Tuesday (12-10-68)	Wednesday (12-11-68)
Stack particulates	None	1,2,3	4
Solid waste*	1,2,3	4,5,6,7	8
Residue†	1	2,3	4
Process water	None	1,2,3, all sources	4, all sources
Stack gases	Grab sample	Grab and composite	Grab and composite

*Even-numbered samples returned to laboratory for analyses.
†All samples returned to laboratory for analyses.

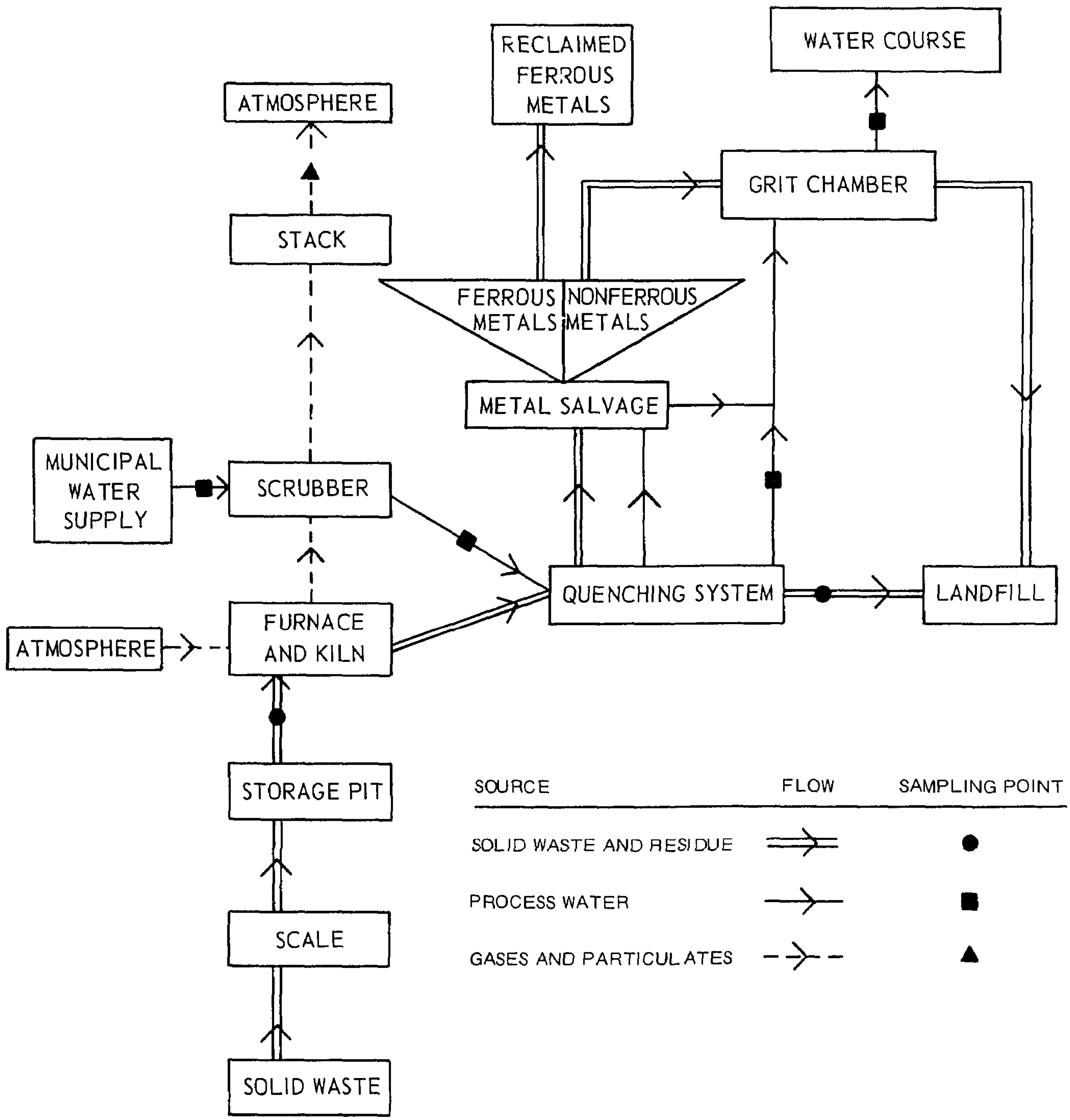


Figure 3. Flow Diagram of the Hartsfield Incinerator.

During the field study, the incoming solid waste and residue was weighed. Because the hammermill was being repaired, no metal was salvaged. Therefore, all the residue went into the residue hopper, there was no wash water from the metal salvage operation, and nonferrous metals were not added to the wastewater in the grit chamber.

Solid Waste

The amount of solid waste burned during the study was determined from the weight records of the solid waste delivered to the plant and an estimate of the amount that was in the storage pit before and after the test period. The burning rate was determined by dividing this amount by the hours of operation during the week. A check of this burning rate was also obtained by noting the time required to burn 110 tons of solid waste set aside for this purpose.

A total of eight samples, representative of the waste being burned, were obtained from the storage pit. These samples were spread on a drop cloth and hand-sorted into nine categories:

Combustibles	Noncombustibles
Food waste	Metal products
Paper products	Glass and ceramics
Plastics, rubber, and leather	Ash, rocks, and dirt
Wood	
Garden waste	
Textiles	

Each category was weighed and the percent by weight on an "as received" basis for each category was determined. Using these percentages, 10 to 15-lb samples were reconstituted from the combustible portion for laboratory analyses. To prevent moisture loss, each of these samples was placed in two plastic bags, one inside the other, and each bag was knotted separately.

The bulked density of the solid waste was obtained by filling a 0.1 cu yd container and obtaining the net weight. No effort was made to compact the wastes during placement in the container.

At the laboratory, the reconstituted combustible portion of the solid waste sample was processed in a hammermill to reduce the maximum particle size to 1 in. The ground product was spread on a plastic sheet and thoroughly mixed. The sample was then successively mixed and quartered and alternate quarters were discarded. This process was repeated until a sample weight of 3 to 4-lb was obtained.

A 100-gram portion of the ground sample was dried at 70 to 75 C to constant weight to determine the moisture content.[1] The sample was then further ground in a Wiley mill until it would pass through a 2-mm mesh sieve. The volatile* and ash fractions[1] and the heat content[2] were then determined. Ultimate analyses[3] for carbon, hydrogen, oxygen, nitrogen, sulfur, and chloride were performed on the ground sample. The ash content of the sample submitted for ultimate analyses was also determined.

Residue

Samples weighing from 70 to 80-lb were collected from the residue conveyor after the stack tests, spread on a drop cloth, and hand sorted

*Material determined by a laboratory analysis.

into four categories. These categories were the unburned combustibles, fines, metals, and glass and rocks. The fines were the unidentifiable material that passes through a 1/2-in. mesh screen. After separation, each category was weighed and the percent by weight on a wet basis of each category was determined. The fines and unburned combustibles were individually sealed in plastic bags to preserve the moisture content and were returned to the laboratory for further analyses. The remaining categories were discarded.

The bulked density of the residue was obtained by filling a 0.03 cu yd container and obtaining the net weight. No effort was made to compact the residue during placement in the container.

At the laboratory, the fines and unburned combustibles were processed in the same fashion as the solid waste samples, with the following exceptions: a 100-gram portion was dried at 100 to 105 C to constant weight to determine the moisture content, and benzoic acid was used as a combustion aid in the calorimeter to determine the heat content. Ultimate analyses were also performed on the ground sample. Sample No. 3 was not separated and was returned to the laboratory for moisture determination only.

Particulate Emissions

On Monday, December 9, 1968, the equipment was assembled and preliminary measurements were made to determine the moisture content, carbon dioxide content, and velocity of the stack gases. Three particulate tests were conducted on Tuesday and one on Wednesday. The sampling train and the sampling and analytical procedures used are described in "Specifications for Incinerator Testing at Federal Facilities."[4]

The sampling ports were located 66 2/3 ft above the stack foundation and approximately 180° apart. Samples were taken from the sampling ports by utilizing a 24-point traverse in the 16 2/3 ft diameter stack. The sampling ports were located 3 diameters from the top of the stack inlet and 8 diameters from the stack exit. The velocity head ranged from 0.01 to 0.08 in. of water. A 3/8-in. nozzle was used. An actual sampling time of 4 min was used at each point.

During the test, whenever excessive accumulations of particulate on the filters hindered isokinetic sampling, the filters were replaced and the test continued to completion.

Stack Gases

During the particulate test, a series of grab samples and a composite sample of the stack gases were taken. The composite sample was collected in a Tedlar bag by slowly filling the bag with stack gases throughout the test period. This sample was used to determine the dry gas composition by using a Burrell Gas Analysis Apparatus[5] (Orsat), Model No. 39-505. Several grab samples were taken during each stack test and analyzed for carbon dioxide with a Dwyer CO_2 Indicator,[6] Model No. 1101, for correlation with the Orsat data.

Process Waters

Each source of process water was sampled to determine its characteristics. These sources were the incoming water (municipal water), scrubber water, scrubber sluicing water, quench water (containing scrubber water), and the plant's final effluent after passing through a grit chamber.

Two grab samples from each source except the scrubber sluicing water were collected during each stack test. A 1-liter composite sample based on equal portions was made from the grab samples for each source for each stack test. These samples were shipped to the laboratory to be analyzed for solids,[7] alkalinity,[7] chloride,[7] hardness,[7] sulfate,[7] phosphate,[7,8] and conductivity.[7] The pH and temperature of each sample was determined in the field. A corning pH meter, Model No. 7, was used.[9]

Cost Analyses

The cost data were obtained by checking all cost records kept by the plant and any administrative group keeping pertinent records. In addition, the personnel who maintained the cost records were questioned to verify and adjust correctly the cost data to fit the Bureau's cost-accounting scheme.

Bacteriological Analyses

The solid waste, residue, quench water, stack gases, fly ash, and tapwater were sampled and analyzed for total bacterial count, heat-resistant spores, coliforms, salmonella, and selected respiratory pathogens. Each source except the tapwater was sampled twice.

A 200-gram sample of solid waste was homogenized for 15 sec in a Waring Blendor containing 1,800 ml of phosphate-buffered water. Serial tenfold dilutions in sterile phosphate-buffered water were made through 10^{-7} after homogenization. For the solid waste, 0.1 ml aliquots from a dilution of 10^{-3} to a dilution of 10^{-7} (yielding 1 log higher dilution) were pipetted into petri dishes for total bacterial count[7] and onto prepared blood agar plates for the propagation of fastidious organisms. Ten-ml aliquots of each dilution were then transferred to tubes and heated in a water bath at 80 C for 15 min for the testing of spore-formers.[7] In addition to aerobic spores, anaerobic spores were tested by use of anaerobic jars. One-ml aliquots from the initial dilutions used for total count and pathogen isolation were filtered through Millipore membranes for the quantitation of total and fecal coliforms.[7] The same procedures were used for the residue, except that the dilutions were pipetted from 10^{-1} through 10^{-3}.

In order to isolate salmonella,[10,11] 30 grams of material were placed into each of two different enrichment media and incubated at 41 C for 18 hr. After incubation, the enrichments were streaked onto selective enteric plates and also incubated at 41 C for 18 hr. Suspected salmonella colonies were tested for biochemical and serological reactions.[12] Selected cultures were sent to the National Communicable Disease Center, Atlanta, Georgia, for serological typing of the salmonella species.

The methods used for analyzing the quench water were similar to those used for the solid waste. For the analyses of total bacterial count, sporeformers, coliforms, and fastidious pathogens, the dilutions ranged from 10^0 to 10^{-6}. Thirty-ml aliquots of quench water were inoculated into each enteric enrichment media for salmonella. The municipal water was tested in a similar manner.

One gram of fly ash was placed into 9 ml of buffered water from which 1 ml and 0.1 ml aliquots were tested for total bacterial count, sporeformers, and for respiratory pathogens.

The stack-sampling device was calibrated to pull 0.62 cu ft per min. The sampling time was 5 min for the first sample and 10 min for the second. The stack gases were forced through 300 ml of buffered water. After sampling, 100 ml of the inoculated buffered water were filtered through a membrane filter for total bacterial count. One-ml amounts were tested for sporeformers and pathogens.

RESULTS

This section presents the data obtained from the analyses of samples taken during the field study of the Hartsfield Incinerator.

Solid Waste

The physical composition data (Table 5) was calculated on an "as received" basis. The densities were calculated on a wet basis as sampled from the storage pit. The values for samples No. 1 through 8 are 160, 265, 210, 160, 180, 205, 250, and 155 lb per cu yd, respectively. The average density was 200 lb per cu yd.

The moisture, volatile, ash, and heat content of the solid waste were obtained from the analyses of the combustible portion only. The results (Table 6) were calculated for the complete sample on the assumption that the noncombustibles contained no moisture or heat and were considered as "ash." The ash and volatile fractions were calculated on a dry basis. The heat and moisture contents were calculated on an "as received" basis. Example calculations are presented in Appendix A.

The data from the ultimate analyses of the solid waste (Table 7) were adjusted to an "as received" basis by assuming that each sample contained only eight constituents. The results were accordingly adjusted on a weight basis to 100 percent.

TABLE 5

SOLID WASTE COMPOSITION

Component	Sample number 1		2		3		4		5		6		7		8		Average (%)
	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	
Combustibles:																	
Food waste	23.0	7.9	32.5	7.8	10.5	5.9	27.2	10.4	37.5	15.1	95.5	18.9	22.5	13.9	77.0	18.1	12.2
Garden waste	4.2	1.5	7.2	1.8	3.8	2.1	4.5	1.7	11.5	4.6	0.8	0.1	1.8	1.1	1.0	0.3	1.6
Paper products	169.5	58.0	245.0	58.8	100.8	56.6	175.7	69.0	142.0	57.1	293.2	58.2	95.8	59.0	230.8	54.1	58.7
Plastic, rubber, leather	5.0	1.7	16.8	4.0	4.5	2.5	7.5	2.9	6.2	2.5	15.5	3.1	4.5	2.8	21.0	4.9	3.0
Textiles	3.8	1.3	3.7	0.9	4.5	2.5	2.8	1.0	7.7	3.1	7.5	1.5	1.8	1.1	12.5	2.9	1.8
Wood	0.5	0.2	1.0	0.2	0.8	0.4	1.0	0.4	1.5	0.6	4.5	0.9	0.2	0.2	1.2	0.3	0.4
Subtotal	---	70.6	---	73.5	---	70.0	---	83.4	---	83.0	---	82.7	---	78.1	---	80.6	100.0
Noncombustibles:																	
Metals	21.5	7.4	31.8	7.6	20.5	11.5	23.5	9.0	18.0	7.2	49.7	9.9	9.5	5.9	42.5	10.0	8.6
Glass and ceramics	48.5	16.6	56.2	13.5	26.3	14.7	14.5	5.5	13.0	5.2	30.8	6.1	20.5	12.6	34.7	8.2	10.3
Ash, dirt, rocks	15.8	5.4	22.5	5.4	6.7	3.8	5.5	2.1	11.5	4.6	6.8	1.3	5.5	3.4	5.0	1.2	3.4
Subtotal	---	29.4	---	26.5	---	30.0	---	16.6	---	17.7	---	17.3	---	21.9	---	19.4	22.3
Grand total	291.8	100.0	416.7	100.0	178.4	100.0	262.2	100.0	248.9	100.0	504.3	100.0	162.1	100.0	425.7	100.0	100.0

TABLE 6

PROXIMATE ANALYSES OF SOLID WASTE

Sample number	Moisture (%)	Volatiles (%)	Ash (%)	Heat (Btu/lb)
2	24.2	58.3	41.7	4,150
4	19.8	75.9	24.1	5,300
6	18.5	74.5	25.5	5,420
8	18.1	71.6	28.4	5,240
Average	20.2	70.1	29.9	5,030

TABLE 7

ULTIMATE ANALYSES OF SOLID WASTE
(Percent)

Sample number	Moisture	Inerts	Carbon	Hydrogen	Oxygen	Sulfur	Chlorine	Nitrogen	Total
2	24.2	30.9	23.0	3.2	17.7	0.1	0.5	0.3	100.0
4	19.8	19.3	28.8	3.9	27.1	0.2	0.6	0.3	100.0
6	18.5	20.8	29.3	3.6	27.0	0.1	0.3	0.4	100.0
8	18.1	23.1	29.3	2.2	26.5	0.1	0.3	0.4	100.0
Average	20.2	23.5	27.6	3.2	24.6	0.1	0.4	0.4	100.0

Residue

The data from the residue separation (Table 8) are on an "as sampled" basis.

TABLE 8

RESIDUE COMPOSITION

Component	Sample number						Average (%)
	1		2		4		
	lb	%	lb	%	lb	%	
Unburned combustibles	0.2	0.2	0.1	0.1	0.0	0.0	0.1
Fines	60.5	74.6	55.5	76.2	50.2	72.8	74.5
Metal	17.0	20.9	14.2	19.6	16.3	23.6	21.4
Glass and rocks	3.5	4.3	3.0	4.1	2.5	3.6	4.0
Total	81.2	100.0	72.8	100.0	69.0	100.0	100.0

The densities of the residue samples were calculated on a wet basis as sampled from the conveyor. The values for samples No. 1, 2, and 4 are 1,365, 1,590, and 1,505 lb per cu yd, respectively. The average density was 1,485 lb per cu yd.

The moisture, volatile, ash, and heat content of the residue were obtained from the analysis of the fines and unburned combustibles only. The results (Table 9) were calculated for the complete sample with the assumption that the glass and metals contained no moisture or heat and were considered as "ash." The moisture content is only representative of the sampling location, which was the residue conveyor. The ash and volatile fractions and the heat content were calculated on a dry basis. Example calculations are presented in Appendix B. Sample No. 3 was not separated and was analyzed for moisture only.

TABLE 9

PROXIMATE ANALYSES OF RESIDUE

Sample number	Moisture (%)	Volatiles (%)	Ash (%)	Heat (Btu/lb)
1	29.5	4.5	95.5	700
2	15.2	2.0	98.0	380
3*	25.9	---	---	---
4	16.8	2.6	97.4	480
Average	21.8	3.0	97.0	520

*Analyzed for moisture only.

The data from the ultimate analyses of the residue (Table 10) were adjusted to a dry basis by assuring that each sample contained only seven constituents, and the results were accordingly adjusted on a weight basis to 100 percent.

TABLE 10

ULTIMATE ANALYSES OF RESIDUE
(percent)

Sample number	Inerts	Carbon	Hydrogen	Oxygen	Sulfur	Chlorine	Nitrogen	Total
1	94.2	5.1	0.3	trace	0.2	0.1	0.1	100.0
2	96.8	2.8	0.2	0.0	0.1	0.1	0.0	100.0
4	96.2	3.5	0.1	0.0	0.1	0.1	0.0	100.0
Average	95.8	3.8	0.2	0.0	0.1	0.1	0.0	100.0

Plant Efficiency

An indication of the plant's performance is obtained by calculating the percent weight reduction, the percent volatile reduction, the percent heat released, and the percent volume reduction (Table 11). These calculations are presented in Appendix C.

Samples of the gas-borne particulates were not analyzed for ash, volatile, or heat content. The wastewater flow was not measured and heat content of the solid material carried by these waters was not determined during the study period. Because these values were not used in the plant-efficiency calculations, the efficiencies shown are slightly higher than they would have been if these values had been included.

TABLE 11

PLANT EFFICIENCY

Type of efficiency	Basis of calculation	Percent
Weight reduction	Dry weights	63
Volatile reduction	Dry weights	98
Heat released	Dry weight of residue and wet weight of solid waste	97
Volume reduction	Wet weights	95

The dry weights of the solid waste, residue, and particulates were used to calculate the percent weight reduction. The percent volatile reduction was also calculated on a dry basis by using the solid waste and residue data. The percent heat released was calculated with the residue data on a dry basis and the solid waste data on an "as received" basis. The percent volume reduction was calculated with the densities on a wet basis.

Process Waters

It was impossible to obtain a sample of the quench water because the scrubber water was continuously discharged to the quench tank. The data (Tables 12 and 13) for the quench water were obtained from the analyses of this mixture of scrubber water and quench water. This mixture was the final effluent from the combustion process. After removal of the heavy solids in the grit chamber, this process water was discharged to a small watercourse.

Instrument Readings

During the stack tests, the instrument panel was monitored to provide information about the plant's operation. Temperatures throughout the combustion unit were monitored at several points. The recirculated preheated air used to dry the solid waste averaged 185 F. The average operating temperature in the ignition chamber and mixing chamber was 1,760 F and 1,685 F, respectively. The temperature in the scrubber after the sprays averaged 265 F. Because water impinged on the thermocouple, this temperature was slightly lower than the temperature of 305 F recorded at the stack-sampling port during the stack tests.

TABLE 12

AVERAGE CHEMICAL CHARACTERISTICS OF WASTEWATER

Source	pH	Temperature (F)	Alkalinity (mg $CaCO_3$/l)	Chloride (mg/l)	Hardness (mg $CaCO_3$/l)	Sulfate (mg SO_4/l)	Phosphate (mg PO_4/l)	Conductivity (μmhos/cm)
Plant influent	8.4	---	100	7	33	1	0.1	46
Scrubber water	2.5-3.0	149	0	295	260	28	12.6	1,360
Scrubber sluicing water	2.9-3.4	148	260	295	420	75	110.0	820
Quench tank effluent	3.9-7.0	119	235	205	290	25	20.9	810
Plant effluent	4.5-6.9	112	105	195	270	33	4.9	750

TABLE 13

AVERAGE SOLIDS CONCENTRATION OF WASTEWATER

Source	Total solids					Suspended solids					Dissolved solids (mg/l)
	Total (mg/l)	Volatiles		Ash		Total (mg/l)	Volatiles		Ash		
		mg/l	%	mg/l	%		mg/l	%	mg/l	%	
Plant influent	55	25	44.6	30	55.4	0	0	0.0	0	0.0	55
Scrubber water	835	345	41.2	490	58.8	90	20	22.2	70	77.8	745
Scrubber sluicing water	5,265	865	16.4	4,400	83.6	4,455	620	13.9	3,835	86.1	810
Quench tank effluent	1,495	425	29.8	1,070	70.2	900	250	30.6	650	69.4	595
Plant effluent	655	185	28.2	470	71.8	85	25	29.4	60	70.6	570

Burning Rate

The total weight of solid waste processed during the study week was 1,800 tons and the total weight of residue remaining after 130 hr of operation was 667 tons. The average daily burning rate was 330 tons per 24 hr, or 13.8 tons per hr. This was 66 percent of the design burning rate. During the previous fiscal year, the plant burned 101,000 tons during 263 operating days for an average of 385 tons per 24 hr, or 16.0 tons per hr, which is 77 percent of the design capacity.

As a means of checking the burning rate of the furnaces during the stack-testing period, 110 tons of solid waste were set aside and burned by both furnaces in 4 hr. This corresponded to a burning rate of 660 tons per 24 hr, or 27.5 tons per hr. Both furnaces were in operation only during the stack tests because of a lack of waste delivered to the plant. Because they were fed at this rate of 27.5 tons per hr during the stack tests, this burning rate was used in all appropriate calculations.

Particulate Emissions

The data from the Orsat analyses (Table 14) of the gas samples obtained from the stack were used to adjust the particulate emissions to 12 percent of carbon dioxide. The particulate concentrations (Table 15) include the weight of material remaining after the evaporation of the impinger water.

TABLE 14

STACK TEST CONDITIONS

Test number	Length of test (min)	Gas composition				Excess air (%)
		CO_2 (%)	O_2 (%)	CO (%)	N_2 (%)	
1	96	4.5	14.6	0.0	80.9	215
2	96	5.0	15.0	0.0	80.0	245
3	96	5.1	14.2	0.0	80.6	200
4	96	5.2	14.4	0.0	80.4	210
Average	96	5.0	14.5	0.0	80.5	220

Cost Analyses

The annual cost (Table 16) of the incinerator was based on a 1-year time period from July 1967 to July 1968.

The financing and ownership costs were based on a capital cost (Table 17) in 1963 of $3,321,779 and a plant life of 30 years. The plant depreciation was calculated on a straight-line basis by dividing the capital cost by the plant life. The same method was used to calculate the vehicle depreciation. The initial vehicle cost was $17,580 and the life was 5 years. Financing was accomplished by issuing a 30-year bond at an interest rate of 3.2 percent. The cost per ton was based on a yearly tonnage of 101,040 tons processed in 263 operating days, or 384 tons per day.

TABLE 15

SUMMARY OF PARTICULATE EMISSIONS

Test number	Particulate emissions							
	gr/scf			lb particulate/1,000 lb dry flue gas			lb/ton waste	lb/hr
	At existing CO_2	At 12% CO_2	At 50% excess air	At existing CO_2	At 12% CO_2	At 50% excess air		
1	0.29	0.76	0.60	0.54	1.43	1.13	7.3	202
2	0.25	0.60	0.57	0.46	1.12	1.07	7.5	207
3	0.35	0.81	0.70	0.65	1.53	1.31	10.1	279
4	0.33	0.74	0.68	0.61	1.39	1.26	9.6	264
Average	0.30	0.73	0.64	0.56	1.37	1.19	8.6	238

TABLE 16

ANNUAL COST ANALYSES
JULY 1967 to JULY 1968

Item	Cost	Cost per ton	Percent of annual cost
Operating costs			
Direct labor and fringe benefits	$202,407	$2.00	29.9
Utilities (electric, gas, sewage, etc.)	65,260	0.65	9.7
Parts and supplies	57,332	0.57	8.5
Vehicle operating expenses	4,188	0.04	0.6
External repair charges	1,999	0.02	0.3
Disposal charges	0	0.00	0.0
Overhead	123,577	1.22	18.3
Subtotal	454,763	4.50	67.3
Financing and ownership costs			
Plant depreciation	110,726	1.10	16.4
Interest	106,859	1.06	15.8
Vehicle depreciation	3,516	0.03	0.5
Subtotal	221,101	2.19	32.7
Total annual cost	675,864	6.69	100.0

TABLE 17

CAPITAL COST

Item	Cost*	Cost per ton of design capacity
Building	$1,034,531	$2,069.06
Equipment	2,137,000	4,274.00
Site improvement	54,000	108.00
Consultant fees	96,248	192.50
Total cost	3,321,779	6,643.56

*1963 dollars.

Several items in the annual cost analyses (Table 16) need further explanation. The actual annual cost of labor was $306,680. The large cost of labor was due to the employment of 50 people in and around the plant. The direct labor cost of $202,407 includes only the salaries of the 33 employees used in the operation of the incinerator. The salaries of the remaining 17 employees used in management and plant site improvement are shown in the overhead. Because the incinerator residue was used as a cover material at the landfill, no disposal charges are included.

The cost of operating and the revenue received from the metal salvage operation were excluded in the cost analyses. During the last year, 2,812 tons of metal were salvaged and sold for a revenue of $32,334. Revenue received from private haulers who dumped waste at the incinerator was excluded. Last year 12,778 tons of solid waste were delivered to the incinerator by private haulers. They were charged \$3.60 per ton, so that the incinerator received a revenue of \$46,000. The cost of the land, \$19,000, was not included in the annual cost analyses.

The cost of repairs and maintenance and its allocation to cost centers was calculated (Tables 18 and 19).

The annual operating cost (Table 20) was allocated to the following cost centers: receiving, which includes items associated with the storage pit, crane, and scale operations; volume reduction, which includes items associated with the furnace operation; and effluent treatment, which includes items associated with residue disposal, air pollution control, and wastewater treatment operations. Allocation of the operating costs into cost centers was achieved through the use of physical factors, such as the number of people involved, power requirements, and the time and material used in each cost center.

TABLE 18

COST OF REPAIRS AND MAINTENANCE

Item	Cost
Labor	\$61,335
Parts	57,332
External charges	1,999
Overhead	37,447
Total	158,113

TABLE 19

ALLOCATIONS FOR REPAIRS AND MAINTENANCE

Cost center	Allocation	Percent of total
Receiving	$39,345	24.9
Volume reduction	85,597	54.1
Effluent treatment	33,171	21.0
Total	158,113	100.0

The labor costs in the projected annual cost at design capacity (Table 21) remain the same because the plant is fully staffed. The financing and ownership costs also remain the same because the expected plant life is 30 years. Again, revenue from private haulers and metal salvage was not included.

Bacteriological Analyses

Samples of solid waste, residue, quench water, stack gases, and fly ash were analyzed for total bacteria, sporeformers, coliforms, salmonella, and selected respiratory organisms (Tables 22 and 23).

From the solid waste sample, other isolations were Klebsiella pneumoniae, Serratia marcesars, and Aerobater aerogens. Isolations were not obtained from the remaining sources that were sampled.

The quench water and tapwater data are expressed as densities per 100 ml of sample. Because these tests are quantitative, when no colonies were isolated the densities are expressed as less than 100 per 100 ml of sample.

TABLE 20

OPERATING COST BY COST CENTERS

Cost center	Operating cost	Percent of operating cost	Percent of annual cost
Receiving:			
Direct labor	$67,470	14.8	10.0
Utilities	6,964	1.5	1.0
Vehicle operating expense	0	0.0	0.0
Repairs and maintenance	39,345	8.7	5.8
Overhead	41,192	9.1	6.1
Subtotal	154,971	34.1	22.9
Volume reduction:			
Direct labor	30,667	6.7	4.5
Utilities	7,724	1.7	1.1
Repairs and maintenance	85,597	18.8	12.7
Overhead	18,725	4.1	2.8
Subtotal	142,713	31.4	21.1
Effluent treatment:			
Direct labor	42,935	9.4	6.4
Utilities	50,572	11.1	7.5
Vehicle operating expense	4,188	0.9	0.6
Disposal charges	0	0.0	0.0
Repairs and maintenance	33,171	7.3	4.9
Overhead	26,213	5.8	3.9
Subtotal	157,079	34.5	23.3
Grand total	454,763	100.0	67.3

TABLE 21

PROJECTED ANNUAL COST AT DESIGN CAPACITY*

Item	Projected annual cost	Cost per ton	Percent of total projected annual cost
Operating costs:			
Direct labor	$202,407	$1.54	28.3
Utilities	84,934	0.65	11.9
Parts and supplies	74,615	0.57	10.4
Vehicle operating expense	5,451	0.04	0.8
External repair charges	2,602	0.02	0.4
Disposal charges	0	0.00	0.0
Overhead	123,577	0.93	17.3
Subtotal	493,586	3.75	69.1
Financing and ownership costs:			
Plant depreciation	110,726	0.84	15.4
Interest	106,859	0.81	15.0
Vehicle depreciation	3,516	0.03	0.5
Subtotal	221,101	1.68	30.9
Grand total	714,687	5.43	100.0

*Design capacity is 500 tons per day.

TABLE 22

BACTERIOLOGICAL DATA

Source and date	Total count			Aerobic spores			Anaerobic spores		
	Dilution	Plate count	Calculated count	Dilution	Plate count	Calculated count	Dilution	Plate count	Calculated count
Solid waste:									
12-10-68	10^{-6}	70	70X10^{6}/gm	10^{-3}	28	28X10^{3}/gm	10^{-3}	13	13X10^{3}/gm
12-11-68	10^{-6}	38	38X10^{6}/gm	10^{-3}	42	42X10^{3}/gm	10^{-2}	4	4X10^{3}/gm
Residue:									
12-10-68	10^{-1}	6	60/gm	10^{-2}	1	100/gm	10^{-2}	0	<100/gm
12-11-68	10^{-1}	5	50/gm	10^{-1}	2	20/gm	10^{-1}	0	<10/gm
Quench water:									
12-10-68	10^{-1}	1	1000/100ml	10^{0}	2	200/100ml	10^{0}	0	<100/100ml
12-11-68	10^{0}	0	<100/100ml	10^{0}	0	<100/100ml	10^{0}	0	<100/100ml
Stack gases:									
12-10-68	10^{0}	0	<0.976/cu ft	10^{0}	1	97.6/cu ft	10^{0}	0	<97.6/cu ft
12-11-68	10^{0}	1	0.489/cu ft	10^{0}	0	<48.9/cu ft	10^{0}	2	97.8/cu ft
Fly ash:									
12-10-68	10^{-1}	0	<10/gm	10^{-1}	0	<10/gm	10^{-1}	0	<10/gm
12-11-68	10^{-1}	1	10/gm	10^{-1}	1	<10/gm	10^{-1}	0	<10/gm
Tapwater:									
12-11-68	10^{0}	0	<100/100ml	10^{0}	1	100/100ml	10^{0}	0	<100/100ml

TABLE 23

COLIFORM DATA

Source and date	Total coliforms			Fecal coliforms			Salmonella
	Dilution	Plate count	Calculated count	Dilution	Plate count	Calculated count	
Solid waste:							
12-10-68	10^{-5}	50	$5X10^{6}$/gm	10^{-4}	24	$24X10^{4}$/gm	not isolated
12-11-68	10^{-6}	21	$21X10^{6}$/gm	10^{-6}	11	$11X10^{6}$/gm	*
Residue:							
12-10-68	10^{-2}	0	<100/gm	10^{-2}	0	<100/gm	not isolated
12-11-68	10^{-1}	0	<10/gm	10^{-1}	0	<10/gm	*
Quench water:							
12-10-68	10^{0}	0	<100/100ml	10^{0}	0	<100/100ml	not isolated
12-11-68	10^{0}	0	<100/100ml	10^{0}	0	<100/100ml	*
Stack gases:							
12-10-68	10^{0}	0	<97.6/cu ft	10^{0}	0	<97.6/cu ft	not isolated
12-11-68	10^{0}	0	<48.9/cu ft	10^{0}	0	<48.9/cu ft	*
Fly ash:							
12-10-68	10^{-2}	0	<100/gm	10^{-2}	0	<100/gm	not isolated
12-11-68	10^{-2}	0	<100/gm	10^{-2}	0	<100/gm	*
Tapwater:							
12-11-68	10^{0}	0	<10/100ml	10^{0}	0	<10/100ml	*

*Not analyzed for Salmonella.

The total bacterial count was done by the membrane-filter method, 100 ml of the inoculated buffered water sample was tested. When equated to cubic feet of stack gas, the quantitative result is expressed as equal to or less than 0.976 per cu ft when the sampling time was 5 min, and equal to or less than 0.489 per cu ft when the sampling time was 10 min.

A maximum of 1 ml of the buffered water sample could be tested by use of the pour plate for the sporeformers. The quantitative value is expressed as equal to or less than 97.6 or 48.9 per cu ft of stack gas when the sampling times were 5 and 10 min, respectively.

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APPENDIX A

Example Calculations for the Ash, Volatile, and Heat Content of the Solid Waste

Using the data from the laboratory analyses of solid waste Sample No. 4 (Table A-1) these example calculations show the methods used to calculate the moisture content, ash and volatile contents, and the heat content of the total sample. The volatile and ash fractions and the heat content are on a dry basis. For these calculations, the assumptions were made that the noncombustibles contained no moisture, no heat, and were considered as "ash."

TABLE A-1

PROXIMATE ANALYSES OF THE COMBUSTIBLE PORTION OF THE SOLID WASTE SAMPLES

Sample number	Moisture (%)	Volatiles (%)	Ash (%)	Heat (Btu/lb)
2	33.0	89.7	10.3	8,425
4	23.7	95.7	4.3	8,335
6	22.4	94.5	5.5	8,440
8	22.5	93.7	6.3	8,375
Average	22.9	94.6	5.4	8,385

The field separation determined a combustible content of 83.4 percent (Text Table 5) on a wet-weight basis. Since moisture in the total sample was assumed to be in the combustible portion only, the percent moisture in the total sample was calculated by the following method:

$$\text{Percent moisture in total sample} = \left(\frac{\text{lb combustibles}}{\text{lb waste}}\right)\left(\frac{\text{lb moisture}}{\text{lb combustibles}}\right)100.0$$

Percent moisture in total sample (No. 4) = (0.834) (0.237) 100.0 = 19.8

Because the volatile and ash fractions are calculated on a dry basis, the percent combustibles must be converted to a dry basis by means of the following equation:

$$\text{Percent dry component} = \left(\frac{\text{lb wet component minus lb moisture in component}}{\text{dry sample weight}}\right)100.0$$

These calculations are summarized in Table A-2.

TABLE A-2

CONVERSION OF THE COMBUSTIBLE AND NONCOMBUSTIBLE DATA TO A DRY BASIS

Component	Wet weight (lb)	Percent by wet weight	Moisture		Dry weight (lb)	Percent by dry weight
			%	lb		
Combustibles	218.7	83.4	23.7	51.8	166.9	79.3
Noncombustibles	43.5	16.6	0.0*	0.0*	43.5	20.7
Total	262.2	100.0	---	---	210.4	100.0

*Assumed.

The percent of volatiles and ash may be calculated as follows:

$$\text{Percent volatiles in total sample} = \left(\frac{\text{lb volatiles}}{\text{lb dry combustibles}}\right)\left(\frac{\text{lb dry combustibles}}{\text{lb dry waste}}\right)100.0$$

Percent volatiles in total sample (No. 4) = (0.957) (0.793) 100.0 = 75.9

Percent ash in total sample = 100.0 minus percent volatiles

Percent ash in total sample (No. 4) = 100.0 - 75.9 = 24.1

The laboratory reports the heat content on a dry basis for the combustibles only. Thus the moisture content and the noncombustibles in the total sample must be accounted for when calculating the heat content of the total sample on an "as received" basis.

$$\text{Heat content of total sample} = \left(\frac{\text{Btu}}{\text{lb dry combustibles}}\right)\left[1 \text{ minus} \left(\frac{\begin{matrix}\text{\% moisture} \\ \text{in total} \\ \text{sample}\end{matrix} + \begin{matrix}\text{\% noncombus-} \\ \text{tibles in} \\ \text{total sample}\end{matrix}}{100}\right)\right]$$

$$\begin{matrix}\text{Heat content of} \\ \text{total sample} \\ \text{(No. 4)}\end{matrix} = (8{,}335)\left[1.0 - \left(\frac{19.8 + 16.6}{100}\right)\right] = \frac{5{,}300 \text{ Btu}}{\text{lb waste}}$$

APPENDIX B

Example Calculations for the Ash, Volatile, and Heat Content of the Residue

Using the data from the laboratory analyses of residue sample No. 1 (Table B-1) these example calculations show the methods used to calculate the moisture content, ash and volatile content, and heat content of the total sample. For each sample, only the fines and unburned combustibles were returned. The volatile and ash fractions and the heat content are on a dry basis.

TABLE B-1

PROXIMATE ANALYSES OF THE UNBURNED COMBUSTIBLES AND FINES

Sample number	Unburned combustibles				Fines			
	Moisture (%)	Volatiles (%)	Ash (%)	Heat (Btu/lb)	Moisture (%)	Volatiles (%)	Ash (%)	Heat (Btu/lb)
1	68.6	34.9	65.1	4,150	39.4	6.9	93.1	1,076
2	52.7	43.2	56.8	5,323	19.9	2.8	97.2	530
4*	---	---	---	---	23.1	3.6	96 4	713
Average	60.6	39.0	51.0	4,736	27.5	4.4	95.6	773

*Unburned combustibles were not found in this sample.

The amount of fines and unburned combustibles found during the field separation was 74.6 and 0.2 percent respectively on wet-weight basis (Text Table 8). The assumptions were made that the glass and rocks and metals contained no moisture, no heat, and were considered as "ash."

Because the moisture in the total sample was assumed to be in the fines and unburned combustibles, the percent moisture in the total sample was calculated by the following method:

$$\text{Percent moisture in total sample} = \left[\left(\frac{\text{lb fines}}{\text{lb residue}}\right)\left(\frac{\text{lb moisture}}{\text{lb fines}}\right) + \left(\frac{\text{lb unburned combustibles}}{\text{lb residue}}\right)\left(\frac{\text{lb moisture}}{\text{lb unburned combustibles}}\right)\right] 100.0$$

$$\text{Percent moisture in total sample (No. 1)} = \left[(0.746)\ (0.394) + (0.002)\ (0.686)\right] 100.0$$

$$\text{Percent moisture in total sample (No. 1)} = 29.5$$

Because the remaining calculations are on a dry basis, the separation data from Text Table 8 must be converted to a dry basis as follows:

$$\text{Percent dry component} = \left(\frac{\text{lb wet component minus lb moisture in wet component}}{\text{total dry sample weight}}\right) 100.0$$

These calculations are summarized in Table B-2.

TABLE B-2

CONVERSION OF THE RESIDUE DATA TO A DRY BASIS

Component	Wet weight (lb)	Moisture (%)	Moisture (lb)	Dry weight (lb)	Percent by dry wt
Fines	60.5	39.4	23.8	36.7	64.0
Unburned combustibles	0.2	68.6	0.1	0.1	0.2
Glass and rocks	3.5	0.0*	0.0*	3.5	6.1
Metal	17.0	0.0*	0.0*	17.0	29.7
Total	81.2	---	---	57.3	100.0

*Assumed.

The percent of volatiles and ash are calculated for the total sample by the following method:

$$\text{Percent volatiles in total sample} = \left[\left(\frac{\text{lb volatiles}}{\text{lb fines}}\right)\left(\frac{\text{lb fines}}{\text{lb residue}}\right) + \left(\frac{\text{lb volatiles}}{\text{lb unburned combustibles}}\right)\left(\frac{\text{lb unburned combustibles}}{\text{lb residue}}\right)\right] 100.0$$

$$\text{rcent volatiles in total sample (No. 1)} = \left[(0.069)\ (0.64) + (0.349)\ (0.002)\right] 100.0$$

Percent volatiles in total sample (No. 1) = 4.5

Percent ash in total sample = 100.0 minus percent volatiles

Percent ash in total sample (No. 1) = 100.0 - 4.5 = 95.5

The heat content is calculated on a dry basis by the following method:

$$\text{Heat content in total sample} = \left(\frac{\text{Btu}}{\text{lb fines}}\right)\left(\frac{\text{lb fines}}{\text{lb residue}}\right) + \left(\frac{\text{Btu}}{\text{lb unburned combustibles}}\right)\left(\frac{\text{lb unburned combustibles}}{\text{lb residue}}\right)$$

Heat content in total sample (No. 1) = (1076) (0.64) + (4150) (0.002) = 700 Btu/lb

APPENDIX C

Plant Efficiency Calculations

These calculations show the methods used to calculate the percent of weight reduction, the percent of volatile reduction, the percent heat released, and the percent of volume reduction. The following data were used:

Residue:	Particulates:	Solid waste:
666.5 tons (wet)	238 lb/hr	1,800 tons (wet)
521.2 tons (dry)		1,435 tons (dry)
21.8 percent moisture		20.2 percent moisture
520 Btu/lb		5,030 Btu/lb
3.0 percent volatiles		70.1 percent volatiles
1,485 lb/cu yd		200 lb/cu yd
130 hr of burning time		

cent weight eduction $= \left[1 - \left(\frac{\text{dry residue weight} + \text{dry particulate weight} + \text{dry weight of wastewater solids*}}{\text{dry weight of solid waste}}\right)\right] 100.0$

·cent weight ·eduction $= \left\{1 - \left[\frac{521.2 + \left(\frac{238 \times 130}{2,000}\right)}{1,435}\right]\right\} 100.0$

·cent weight ·eduction $= \left[1 - \left(\frac{536.7}{1,435}\right)\right] 100.0 = 62.7$

·cent volatile ·eduction $= \left[1 - \left(\frac{\text{weight of dry volatiles in residue} + \text{weight of dry volatiles in particulates*} + \text{weight of dry volatiles in wastewater solids*}}{\text{dry weight of volatiles in solid waste}}\right)\right] 100.0$

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*Not measured.

$$\text{Percent volatile reduction} = \left[1 - \left(\frac{(0.03)(521.2)}{(0.701)(1,435)}\right)\right] 100.0$$

$$\text{Percent volatile reduction} = \left[1 - \left(\frac{15.6}{1,005}\right)\right] 100.0 = 98.5$$

$$\text{Percent heat released} = 1 - \left[\frac{\left(\text{heat content of dry residue} \times \text{weight of dry residue}\right)}{(\text{heat content of solid waste})\ (\text{weight of solid waste})}\right.$$

$$+ \frac{\left(\text{heat content of particulates*} \times \text{weight of particulates*}\right)}{\text{heat content of solid waste} \quad \text{weight of solid waste}}$$

$$\left. + \frac{\left(\text{heat content of wastewater solids*} \times \text{weight of wastewater solids*}\right)}{(\text{heat content of solid waste})\ (\text{weight of solid waste})}\right] 100.0$$

$$\text{Percent heat released} = \left[1 - \left(\frac{(520)\ (2,000)\ (521.2)}{(5,030)\ (2,000)\ (1,800)}\right)\right] 100.0$$

$$\text{Percent heat released} = \left[1 - \left(\frac{5.42 \times 10^8}{181.1 \times 10^8}\right)\right] 100.0 = 97.1$$

$$\text{Percent volume reduction} = \left\{1 - \left[\frac{\left(\frac{\text{total wt of wet residue}}{\text{density}}\right) + \left(\frac{\text{wt of particulates*}}{\text{density*}}\right) + \left(\frac{\text{wt of solids in wastewater*}}{\text{density*}}\right)}{\left(\frac{\text{wt of solid waste "as received"}}{\text{density}}\right)}\right]\right\} 100.0$$

$$\text{Percent volume reduction} = \left\{1 - \left[\frac{\left(\frac{666.5 \times 2,000}{1,485}\right)}{\left(\frac{1,800 \times 2,000}{200}\right)}\right]\right\} 100.0$$

$$\text{Percent volume reduction} = \left[1 - \left(\frac{897.6}{18,000}\right)\right] 100.0 = 95.0$$

*Not measured.