OSWØØØ797

SMALL MODULAR INCINERATOR SYSTEMS WITH HEAT RECOVERY:

A TECHNICAL, ENVIRONMENTAL, AND ECONOMIC EVALUATION

Executive Summary

This report (SW-797) was prepared under contract for the Office of Solid Waste by Richard Frounfelker.

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

An environmental protection publication (SW-797) in the solid waste management series. Mention of commercial products does not constitute endorsement by the U.S. Government. Editing and technical content of this report were the responsibilities of the Resource Recovery Division of the Office of Solid Waste.

Single copies of this publication are available from Solid Waste Information, U.S. Environmental Protection Agency, Cincinnati, OH 45268.

FOREWORD

This report is a summary of a technical, environmental, and economic evaluation of two small modular incineration-heat recovery facilities: one in the plant of the Truck Axle Division of Rockwell International Corporation in Marysville, Ohio, and the other in the Municipal North Shore Energy Plant in North Little Rock, Arkansas. The evaluation program was sponsored and directed by the Environmental Protection Agency (EPA) and the California State Solid Waste Management Board and was conducted under EPA Contract No. 68-01-3889 by Systems Technology Corporation (SYSTECH), Xenia, Ohio. The report was prepared by Richard Frounfelker, Staff Engineer of SYSTECH, for submittal to EPA.

The report explains the controlled air concept of the modern two-chamber incinerator, chronicles its development and application, and summarizes currently available systems for small-scale usage. Then the report details each of two facilities selected for the evaluation and presents the technical, environmental, and economic evaluation for each facility. In addition, the report projects the operating costs for the two facilities under optimum operating conditions and for municipal and industrial facilities in general.

Since the two evaluated facilities operate under different conditions with one burning municipal waste and the other industrial waste, they were not compared. Moreover, the reader is cautioned not to draw comparative conclusions.

The full report, intended for design engineers and other specialists requiring in-depth data, will be made available for purchase from the National Technical Information Service, Springfield, VA 22161.

ABSTRACT

This program involved a technical, environmental, and economic assessment of the feasibility of utilizing small modular incinerator systems for solid waste disposal in municipal and industrial applications. The assessment was implemented by (1) overviewing the state-of-the-art, (2) selecting two operational sites (one municipal and one industrial) representative of the state-of-the-art, and (3) subjecting these two sites to a rigorous field evaluation. The two facilities selected for this study were a municipal incinerator plant with a Consumat system in North Little Rock, Arkansas, and an industrial incinerator facility with a Kelley system in the plant of the Truck Axle Division of the Rockwell International Corporation in Marysville, Ohio. This selection was the result of a nationwide survey to find those two facilities which best satisfied several criteria. The principal selection requirements were a solid waste processing module with heat recovery and a capacity of 50 tons or less per day and its being representative of current technology, designs, and operational procedures.

Preparatory to the detailed description and evaluation of the two facilities, the report explains the controlled air concept of the two-chamber incinerator and briefly discribes its development and application. In addition, as a technical guide for the review and selection of currently available systems, the report details, according to available information, the 17 sources whose modular incinerators represent state-of-the-art technologies.

The technical evaluation presents the results of three weekly field tests at each site. The data was used to calculate the following for each system: the mass balance, the incinerator efficiency, the energy balance, the heat recovery efficiency, and the overall effectiveness of the system as a solid waste disposal facility.

The environmental evaluation presents the effects of the incinerator-heat recovery operation on the environment, specifically the atmosphere, the discharged process water, the landfills for refuse disposal, and the plant areas. An EPA Level One assessment presents a detailed analysis of the emissions.

The economic evaluation presents a detailed accounting of facility (1) capital costs, (2) operating and maintenance costs, (3) revenues, and (4) net operating costs.

Since the two systems differ in many respects and operate on dissimilar waste streams, they are not compared.

This report was submitted in fulfillment of Contract Number 68-01-3889 by Systems Technology Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1977 to March 1979.

CONTENTS

CONTENTS (concluded)

FIGURES

FIGURES (continued)

FIGURES (concluded)

TABLES

TABLES (concluded)

ACKNOWLEDGMENT

This evaluation program was performed under EPA Contract No. 68-01-3889, "Technical and Economic Evaluation of Small Modular Incinerator Systems with Heat Recovery."

The EPA project officer was David B. Sussman of the Office of Solid Waste, Washington, D.C. The coordinator for the California State Solid Waste Management Board was Robert Harper, Waste Management Engineer.

On behalf of Systems Technology Corporation, the author is pleased to acknowledge the guidance and support of David B. Sussman and Robert Harper and the cooperation of the plant engineers and staff members and the manufacturer representatives who generously assisted with the testing at the Rockwell International Corporation facility in Marysville, Ohio, and at the North Shore Energy Plant in North Little Rock, Arkansas.

The author is also grateful to Arthur Young & Company for its collaboration in the economic evaluation and to all his company colleagues who contributed to the collection of the test data and the development of this report. Of the latter, the author is particularly thankful to Gerald Degler, Ned Kleinhenz, and Rick Haverland.

SECTION 1

INTRODUCTION AND SUMMARY

PROGRAM OBJECTIVE, BACKGROUND, AND SCOPE

This study consisted of a technical, environmental, and economic evaluation of small modular incinerator systems with the overall objective being to determine the feasibility of their usage for solid waste disposal and heat recovery in municipal and industrial environments. The evaluation aspects of this report include (1) sufficient data and procedures to assess all technical, environmental, and economic aspects of small modular incineration-heat recovery systems; (2) a technical guide for the review and selection of currently available systems; (3) sufficient manufacturer and field test data to apply and/or adapt the current systems to particular needs; and (4) a data base for the future analysis and appraisal of advanced systems.

Recent technological advances and economic and environmental developments prompted the Office of Solid Waste Management of the Environmental Protection Agency to initiate this study. Some of the more significant advances are as follows: First, the incinerator manufacturers have successfully developed the two-chamber, controlled air incinerator for optimum efficiency and significantly reduced particulate emissions. Second, they have designed incinerators with integrated control systems to ensure their economic feasibility and efficient operation. Third, the small modular incinerator features simple and reliable operation, low maintenance costs, and payback frequently within 3 to 4 years (primarily in an industrial application).

Several economic and environmental factors have given added impetus to the attractiveness of the small modular incinerator with heat recovery. For example, municipalities are finding that such incinerators can address the problems (1) of rising landfill costs or rapidly diminishing landfill sites, (2) of complying with environmental pollution control regulations, and (3) of offsetting capital costs for waste disposal equipment through the revenues of recovered energy products and the savings of eliminated landfill expenses. Similarly, industries are seeing the advantages of burning waste rather than oil or gas (1) to recover the waste energy, (2) to save the expenditures for landfill disposal, (3) to meet the threats of fuel curtailments and rising costs, (4) to gain tax credits, and (5) to comply more readily with environmental control regulations. Furthermore, public opinion and government enactments lend strong encouragement and support to the widespread usage of the small modular incinerator with heat recovery because of its resource recovery and environmental control potential.

This report explains the controlled air concept of the modern two-chamber incinerator, chronicles its development and application, and summarizes currently available systems designed for small-scale usage. Then the report details each of two selected small-scale facilities and presents the technical, environmental, and economic evaluation of each, but in no way attempts to compare the two different systems. Finally, the 1978 economic data of the two evaluated facilities were adapted to estimate the operating costs at municipal and industrial facilities in general.

The two small incinerator facilities selected for intensive evaluation were a municipal incinerator plant in North Little Rock, Arkansas, and an industrial incinerator in the plant of the Truck Axle Division of the Rockwell International Corporation in Marysville, Ohio. In the selection of the two facilities, each had to meet three criteria: (1) a capacity designed for 50 tons or less of solid waste per day; (2) its integration with heat recovery equipment; and (3) its incorporation of the principles, designs, and operational procedures of current technology.

CURRENT MODULAR INCINERATOR TECHNOLOGY

Concept

The modular incinerators, generally consisting of a primary and a secondary combustion chamber, employ controlled air techniques to reduce the amount of air required for combustion in the primary chamber and to lower the level of their particulate emissions. These incinerators originated in the late 1960's, and their technologies and applications expanded in the 1970's.

The name "modular" was derived from the following: (1) each unit is identical, (2) each unit operates independently, and (3) one or more units can be readily integrated in an existing system as the waste demand increases. The terms "starved air," "substoichiometric," and "pyrolitic" denote the different combustion processes in the primary chamber. Sometimes these terms are used to denote the entire incinerator system.

Current Systems

A survey identified 16 manufacturers that produce incinerators capable of processing 454 to 1816 kg/hr (1000 to 4000 lb/hr) of industrial and/or municipal solid waste and of recovering the heat for energy production. The primary chambers in these incinerators operate under starved air (substoichiometric) or excess air combustion conditions. The incinerator systems can be grouped in five basic physical configurations. The larger systems have (1) automatic feeds consisting of loading hoppers, conveyors, and screws; (2) loading rams, moving grates, augers, and rotating chambers for continuous refuse flow through the primary chamber; and (3) heat recovery systems with fire or water tube boilers and other heat exchangers.

SUMMARY OF SELECTED SYSTEMS

Technical Capabilities

Performance--

At the North Little Rock municipal facility, where a Consumat incineration-heat recovery system is operative, the Consumat module proved capable of recovering about 55 percent of the energy burned and of reducing the municipal solid waste 55 percent by weight and 94 percent by volume. Over the past 3 years, 13 Consumat incinerators have been burning municipal waste. Four of these incinerators are integrated with heat recovery equipment.

At the Marysville industrial facility, where a Kelley incineration-heat recovery system is operative, the Kelley module proved capable of recovering about 55 percent of the energy burned and of reducing industrial refuse 95 percent by volume. Over the past four years, seven similar systems have been burning industrial waste. In addition, four units are burning municipal waste but without heat recovery.

The designs of both systems are still evolving. Each new facility introduces technological advances based on the experience gained from the previous installations. These technological improvements have advanced to the stage where the systems can burn waste and produce energy with satisfactory reliability.

Maintenance and Reliability--

The routine maintenance of both the Consumat and the Kelley systems consists principally of small refractory repairs and replacement of thermocouples and other switches, door seals, and motors. The maintenance requirements specific to each system are the weekly removal of soot from the boiler tubes in the Consumat system and the weekly cleaning of the induced draft fan blades and at least the semiannual cleaning of the boiler tubes in the Kelley system. The major maintenance requirement of both systems is the refractory replacement in 3 to 8 years, depending on the operational mode. In addition, because of its more extensive control system, the Consumat module requires more maintenance on the automatic control, hydraulic, and residue removal systems. In general, modules burning municipal waste require more maintenance than those burning industrial refuse. In addition, more operational interruptions must be anticipated when burning municipal waste because of the jams caused by large metal objects in the waste and the greater frequency of the above-mentioned routine maintenance. Moreover, the slag formed from the fusion of glass and metals frequently plugs air injection ports and degrades the refractory.

Operation--

The Consumat system with its 100-TPD capacity at the North Little Rock facility required nine personnel: one supervisor, one clerk, one truck driver, and two operators for each of three shifts. The Kelley system at the Marysville facility with its capacity of 12 TPD and limited operational usage of two shifts, 5 days per week, required only one full-time operator per shift. As additional part-time assistance was required, it was usually supplied by the plant maintenance staff. Neither facility required waste preprocessing, although operators at both facilities removed such materials as pipe and wire before refuse loading and hand-loaded some materials into the incinerator hopper to prevent jamming.

The Consumat system includes (1) a remotely controlled display panel to instruct the loading operator on how large a load to collect and when to deposit it into the incinerator hopper, (2) an automatically modulated air control to maintain a desired temperature in each of the two combustion chambers, and (3) an automatic ash removal system. The Kelley system allows the operator to judge the size and frequency of each refuse loading. With the airflow preset to handle a specific waste stream, only a high temperature lockout on the Kelley system prevents extreme refuse overloading. In both systems, overfeeding causes high temperatures in the secondary chamber, excessive gaseous emissions, and wasted energy. On the other hand, underfeeding reduces the system throughput rate, and the resultant low chamber temperatures may require burning auxiliary fuel. Therefore, proper feeding of the incinerators to ensure proper combustion is essential for optimum incinerator performance.

Environmental Acceptability

Emissions Compliance--

Neither facility had a high enough daily refuse consumption, i.e., over 50 tons per day per module or 250 tons per day per facility, to be considered under the Federal standard of performance for new stationary sources or the prevention of significant deterioration regulations. Therefore, a new source review was not required during the preconstruction planning. Both plants complied with their respective state-imposed emissions standards and building permits. If either facility had more than a daily 250-ton throughput, it would have been subject to a new source review and would have required the best available emissions control such as an electrostatic precipitator or a fabric filter.

At both facilities, the gaseous emissions related directly to the size of the load fed into the incinerator. The sulfur and nitrogen oxide levels in the stack emissions were negligible. At the North Little Rock facility, the chloride emissions varied from 100 to 600 mg/m^3. No direct relationship was evidenced between the loading or sizing of the particulate emissions and the modulating air supply.

EPA Level 1 Analysis--

At both facilities, 90 percent of the stack particulates were less than 7 micrometers in diameter; the stack emissions had a wide range of metals and halogens in minute amounts; and the residue had a high pH and contained traces of many metals such as zinc, tin, lead, and cadmium.

Economic Effectiveness

Capital Cost--

For an incinerator with heat recovery, the capital cost of refuse processed daily was computed at $15,000 per ton (based on 1977 dollars).

The relationship between the capital cost per ton and the incinerator capacity was found to be nearly linear up to a 200-TPD capacity. A 12-TPD industrial system would cost $220,000 to $300,000, while a 100-TPD municipal system with a 300-meter steam condensate return line would cost about $1,500,000 (based on 1977 dollars).

Operational Cost--

On the basis of the test data, the optimum annual operating cost (based on 1978 dollars) of a 100-TPD municipal facility would be $370,000. With optimum steam revenues and tipping fees of $305,000, the net annual operating cost of this facility would be $65,000 or $3.01/Mg ($2.72/ton) of refuse processed. For a 12-TPD industrial facility, the optimum annual operating cost (based on 1978 dollars) would be $117,944. Applying credits for disposal savings and energy savings of $82,620 and $139,594, respectively, results in a net savings of $104,270 or $31.94/Mg ($28.96/ton) of refuse processed. The facility finances are highly sensitive to the refuse processing rate, the operating time, and the steam sales price.

SECTION 2

THE SMALL MODULAR INCINERATOR

CONTROLLED AIR INCINERATION

Introduction

During the 1960's virtually all operational incinerators were still uncontrolled air units. To ensure a high degree of combustion in these incinerators, air was supplied in fixed amounts with a volume considerably more than that required for stoichiometric combustion. Consequently, large quantities of both combustible and inert particulates were discharged to the atmosphere with the exiting flue gases.

In the late 1960's the industry introduced the controlled air incinerator, that is, an incinerator with an afterburner or an incinerator with a primary and a secondary combustion chamber. The term "controlled air" denotes that the air flowing into the two combustion chambers is regulated at a minimum rate. The lower airflow requires less motor horsepower on the fans and reduces the amount of the particulates entrained in the exiting flue gases.

The first, or primary, chamber is also called the lower chamber, the combustion chamber, or the gasifier. Similarly, the second, or secondary, chamber is also called the upper chamber, the ignition chamber, the afterburner, or the thermal reactor.

The term "modular" as a descriptor for the controlled air incinerator developed as follows: The controlled air incinerators designed for burning commercial and industrial waste have been constructed of integral components, one for the primary chamber, one for the secondary chamber, and so on. Each component has been assembled and packaged in the factory for immediate on-site installation. Only electrical, fuel, water, and gas duct connections are required at the installation site. When the waste volume has exceeded the capacity of the installed units, additional incinerators have been incorporated to meet the increased demand. Since the additional incinerators are constructed and function as modules, the integrated units became known as modular incinerators. While the capacity of the modular incinerators has increased from 1 to 4 tons of waste per hour, most of the components are still completely assembled and packaged in the factory for immediate on-site installation.

Controlled air incinerators are grouped under two main categories according to the degree of combustion, complete or partial, in the primary chamber. Since the complete combustion requires excess air and the partial combustion needs substoichiometric conditions, the categories are excess air incinerators and substoichiometric, or starved air, incinerators (see Figure 1).

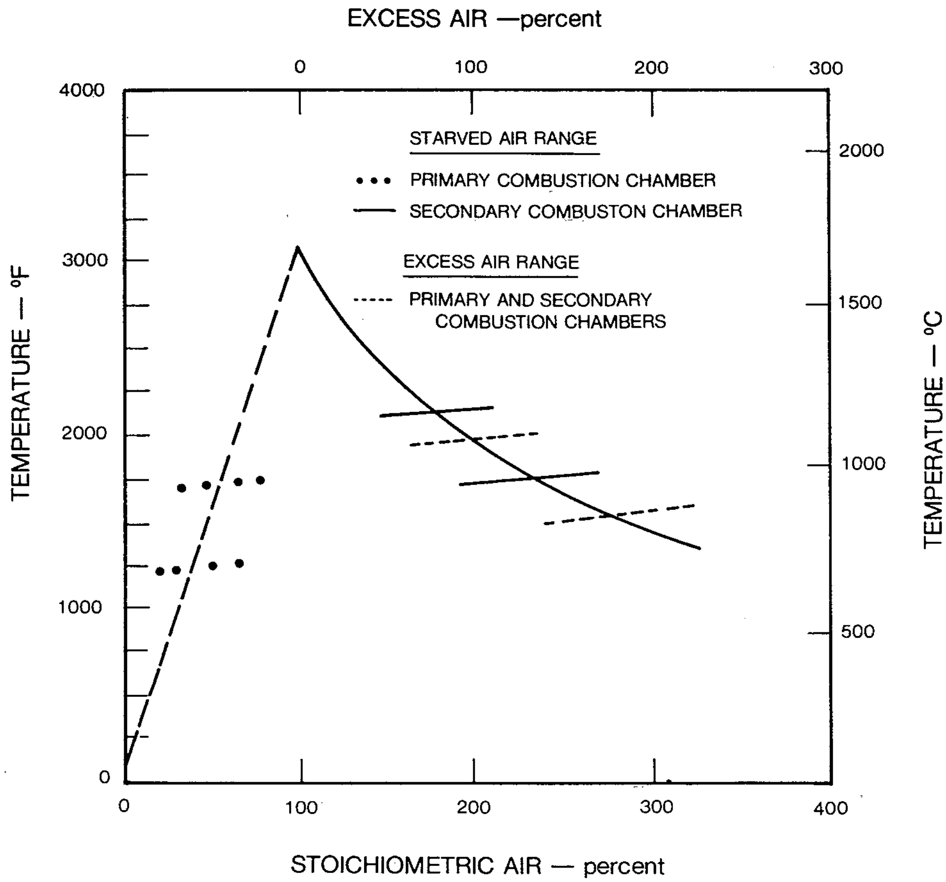


Figure 1. Operational ranges (stoichiometric air percentage and temperature) for controlled air incinerators.

In addition to the airflow regulation, the combustion process is also controlled by varying the waste feed rate and, in some incinerators, by spraying water into the primary chamber.

Feeding Mechanism

The waste to be burned is fed into the primary chamber in controlled batches and at prescribed intervals. The feed rate is usually dictated by the temperature in the secondary chamber. Except for the removal of white goods and large metals, the waste stream usually need not be preprocessed before it enters the primary chamber.

Primary Chamber

During start-up of the substoichiometric, or starved air, incinerator, one or two auxiliary burners in the primary chamber progressively dry, volatize, and ignite the waste. When the combustion rate is sufficient to sustain partial oxidation reactions, the auxiliary burners are shut off. The partial oxidation is maintained by supplying the primary chamber with less air than that needed for the complete combustion of the gases and chars. The combustible gases and particulates generated in the primary chamber flow into the secondary chamber where combustion is completed. Any unburned carbon in the primary chamber is removed with the ash and other inert materials.

During start-up of the excess air incinerator, an auxiliary burner in the primary chamber dries, volatizes, and ignites the waste. With 75 to 150 percent excess air introduced under, over, and beside the waste, the combustion is sustained sufficiently to turn off the burner and to burn both the gas by-products and the combustible solids of the initial and subsequent waste batches. As the gases flow into and through the secondary chamber, any remaining combustibles are burned to completion.

Secondary Chamber

In the substoichiometric, or starved air, incinerator, the secondary chamber is initially heated by an auxiliary burner. This burner ignites the partially oxidized combustibles flowing from the primary chamber into the secondary chamber. Then as the burning gases mix with additional air, complete combustion is achieved and the flue gas temperatures increase to 760° and 888°C (1400° and 1600°F). As the combustion generating this heat is self-sustaining, the burner is automatically shut off by a temperature control device and remains off while the unit is maintained at the designed operating level.

In the excess air incinerator, no auxiliary burner is needed in the secondary chamber since the high temperature of the entering gases and the addition of more air is sufficient to sustain combustion. The excess air introduced into the chamber ranges from 75 to 150 percent of the air needed for combustion. Excess air, turbulence, and retention time collectively provide the conditions for the nearly complete burning of all the combustible gases and particulates.

Temperature Control

The temperature in the primary chamber is sensed by thermocouples. Temperature control is maintained at a set point with a 37.7°C (100°F) control band by varying the waste feed rate and the amount of air injected and by spraying the chamber with a water mist. While the set points vary with the incinerator manufacturer and the waste to be burned, they generally range from 649° to 982°C (1200° to 1800°F).

The temperature in the secondary chamber is also sensed by thermocouples with set points. When the chamber temperature reaches the set points, the thermocouples activate controllers which modulate airflow dampers and turn the burner on and off.

Residue Removal

Ash and other noncombustible residue which settle on the hearth of the primary chamber after the combustion process are periodically removed by manually or automatically operated systems. In the manual system the operator scoops out the ash (by shovel or front-end loader) after the unit has been shut off and cooled down. In the automatic system the ash is pushed or forced ahead of the burning waste until it exits the chamber, generally through a drop chute into a water-sealed pit or an air-lock chamber.

Energy Recovery

Several incinerator systems incorporate water or fire tube boilers to recover the thermal energy from the flue gases exiting the secondary chamber. Either an induced draft fan in the gas stream or an aspirator fan outside the gas stream draws the flue gas through the boiler.

Waste Consumption

The waste consumption capacity of the controlled air incinerators varies greatly with the waste characteristics. The energy content is the most important factor in determining the capacity. The modular units are designed to burn a specific amount of energy per hour; therefore, the higher the energy content per unit mass, the slower the feed rate. The incinerator capacities in industrial plants and those in municipal plants are conventionally expressed in waste feed rates of kilograms (pounds) per hour and megagrams (tons) per day, respectively.

The capacities of the substoichiometric, or starved air, incinerators range from 10.9 to 45.4 Mg/day (12 to 50 TPD) while those of the excess air incinerators range from 10.9 to 272.1 Mg/day (12 to 300 TPD).

Stack Emissions

Since the controlled air combustion in the two chambers burns most, but not all, of the combustible gases and particulates, the stack emissions without any additional air pollution equipment will contain some unburned carbon, as well as inert particles and vapors.

Industrial incinerators that burn a consistent waste have been designed and operated so that their stacks would not require additional emission control equipment. In contrast, municipal incinerators that burn a highly heterogeneous and changing waste may require additional air emission control equipment to meet the applicable state standard since it is difficult to maintain combustion at steady-state conditions, and, consequently, to keep emissions at prescribed levels.

HISTORY OF CONTROLLED AIR INCINERATION

Introduction

During the period from 1960 to 1970, incineration was a recognized economical method of solid waste disposal. A reported 265 to 299 incineration plants were in operation across the United States.

The enactment of the Clean Air Act in 1970 began the closure of the incineration facilities because of a reluctance on the part of the facility owners to add air pollution control equipment to meet the more stringent air emissions standards. Closure due to the excessive cost of installing air emission control devices has prompted most cities to seek a more economical method of solid waste disposal.

As the incineration facilities closed, many of the incinerator companies also folded. As the uncontrolled (excess) air incinerator industry diminished, the controlled air incinerator business correspondingly increased. Many of the smaller modular incinerators were first developed by manufacturers of the larger uncontrolled air incinerators.

Design Evolution

The first-generation models of the controlled air modular incinerator were small refractory-brick-lined primary chambers with a vertical afterburner chamber and stack combination. These incinerators had capacities in the range of 45.4 to 318 kg/hr (100 to 700 lb/hr) when burning commercial or industrial waste. The controls on these incinerators were minimal, i.e., on/off switches for the burner and preset air blowers. The primary uses for the incinerators were to burn waste generated from hospitals, stores, and restaurants.

Subsequently, the afterburner stack was replaced by a larger secondary chamber, and the capacity of the units was increased to 1135 kg/hr (2,500 lb/hr). The control of the temperature and airflow in the secondary chamber permitted modulating the burner or even shutting it off after a temperature high enough for self-sustaining combustion of the gases was reached. This control minimized the consumption of auxiliary fuel since continuously operating units do not require afterburner fuel once they have reached operating temperature and are maintained at designed operating levels.

The earlier units were loaded through a door before the unit was ignited. Because of the positive pressure in the chamber and the presence of pyrolysis gases, opening the door while the waste was burning resulted in flames leaping out. Double doors and temperature lockouts were developed to prevent the operator from being injured by these flames. Later, a slight negative pressure was induced in some models to prevent flame escape as the doors were opened. On the larger units, the loading system advanced from the door loaders to an enclosed hopper and ram module. The latter equipment allowed more waste to be quickly and safely loaded into the primary chamber. Pneumatic feeds for small-particle waste and pump feeds for liquid waste were also developed.

Ash in the primary chamber was originally removed manually after the chamber had cooled sufficiently. While automatic, continuously operating residue removal systems have been developed for the larger incinerators, most of the smaller incinerators (those with capacities less than 317.8 kg/hr [700 lb/hr]) still have the ash removed manually.

Although the larger modular incinerators were integrated with heat recovery systems, their high cost initially made their sale difficult. However, with oil and gas prices increasing and curtailments brought on by the recent energy crisis, the waste incinerator with heat recovery became an economical alternative to landfills and conventional fuels. Incorporating the heat recovery system with the incinerator necessitated the addition of expanded control systems.

CURRENTLY AVAILABLE MODULAR INCINERATORS

In a survey to determine the currently available modular incinerators that would represent state-of-the-art technologies and designs and various configurations, the manufacturers' brochures were reviewed, and conversations were held with manufacturer representatives to supplement the information in the sales literature. Most of the manufacturers have several incinerator and heat recovery models with capacities ranging from 15.4 to 90.7 Mg (17 to 100 tons) per day. Table 1 presents pertinent information about the different systems, and Table 2 lists the manufacturers' addresses and telephone numbers.

After analyzing the survey results, the incinerator systems were grouped under five categories:

(1) Two horizontal cylindrical chambers with one above the other, as manufactured by Environmental Control Products, Comtro, Morse Boulger, Econo-therm, Kelley, Consumat, and Smokatrol (see Figure 2).

(2) Two horizontal rectangular chambers with one above the other, as manufactured by Washburn & Granger, Basic, and Simonds (see Figure 3).

(3) Two vertical cylindrical chambers with one above the other, as manufactured by Burn-Zol and Lamb-Cargate (see Figures 4 and 5).

(4) A rotary primary chamber or a fixed primary chamber with a rotary grate or auger and a fixed secondary chamber, as manufactured by Scientific Energy Engineering, Giery, and C. E. Bartlett (see Figures 6, 7, and 8).

(5) Two horizontal rectangular chambers with one after the other, as manufactured by Clear Air (see Figure 9).

TABLE 1. MANUFACTURERS OF MODULAR INCINERATORS

Manufacturer	Incinerator type: municipal no. with heat recovery	municipal no. without heat recovery	industrial no. with heat recovery	industrial no. without heat recovery	Air emissions control equipment normally employed	Combustion process	Capacity range Mg/day (TPD)
Basic	0	0	6	6		#	33 (36) to 136 (150)
Burn-Zol	0	0	1	0	X	†	up to 22 (24)
C.E. Bartlett	0	0	0	19	X	#	up to 35 (38)
Clear Air	0	3	0	0	X	#	44 (48) to 272 (300)
Comtro	0	3	3	N		†	up to 22 (24)
Consumat	4	13	4	N	X	†	up to 45 (50)
Econotherm	0	0	4	N		†	up to 29 (32)
ECP	1	0	14	N		†	up to 43 (48)
Giery	1	0	0	0	X	#	22 (24) to 65 (72)
Kelley	0	6	49	N		†	up to 22 (24)
Lamb-Cargate	0	0	2	0		†	up to 181 (200)
Morse-Boulger	0	4	1	0	X	#	up to 227 (250)
SEE	0	1	0	0	X	†	up to 136 (150)
Simonds	0	0	7	N		#	up to 27 (30)
Smokatrol	0	0	1	N		†	up to 37 (30)
Washburn	1	1	0	0	X	†	up to 22 (24)

\# Excess air incineration.

† Starved air incineration.

N Numerous.

TABLE 2. ADDRESSES AND TELEPHONE NUMBERS OF MODULAR INCINERATOR MANUFACTURERS

Basic Environmental Engineering, Inc. 21W161 Hill Glen Ellyn, Illinois 60137 (312) 469-5340	Giery Company, Inc. P.O. Box 17335 Milwaukee, Wisconsin 53217 (414) 351-0740
Burn-Zol P.O. Box 109 Dover, New Jersey 07801 (201) 361-5900	Kelley Company, Inc. 6720 N. Teutonia Avenue Milwaukee, Wisconsin 53209 (414) 352-1000
C. E. Bartlett-Snow 200 West Monroe Chicago, Illinois 60606 (312) 236-4044	Lamb-Cargate P.O. Box 440 1135 Queens Avenue New Westminster, British Columbia V3L 4Y7 (604) 521-8821
Clear Air, Inc. P.O. Box 111 Ogden, Utah 84402 (801) 399-9828	Morse-Boulger 53-09 97th Place Corona, New York 11368 (212) 699-5000
Comtro Division 180 Mercer Street Meadville, Pennsylvania 16335 (814) 724-1456	Scientific Energy Engineering, Inc. 1103 Blackstone Building Jacksonville, Florida 32202 (904) 632-2102
Consumat P.O. Box 9574 Richmond, Virginia 23228 (804) 746-4120	Simonds Company P.O. Drawer 32 Winter Haven, Florida 33880 (813) 293-2171
Econo-Therm 1132 K-Tel Drive Minnetonka, Minnesota 55343 (612) 938-3100	U.S. Smelting Furnace Company (Smokatrol) P.O. Box 217 Belleville, Illinois 62222 (618) 233-0129
Environmental Control Products P.O. Box 15753 Charlotte, North Carolina 28210 (704) 588-1620	Washburn and Granger 85 5th Avenue Patterson, New Jersey (201) 274-2522
Environmental Services Corporation P.O. Box 765 Crossville, Tennessee 38555 (615) 484-7673	

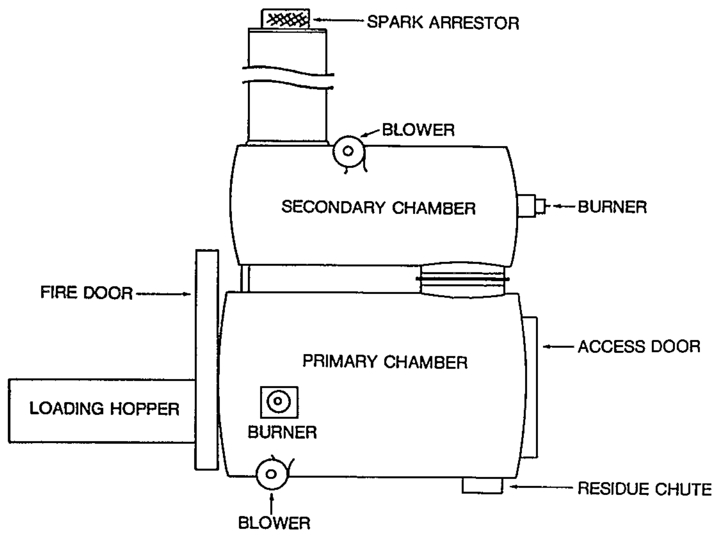


Figure 2. Configuration of two horizontal cylindrical chambers with one above the other.

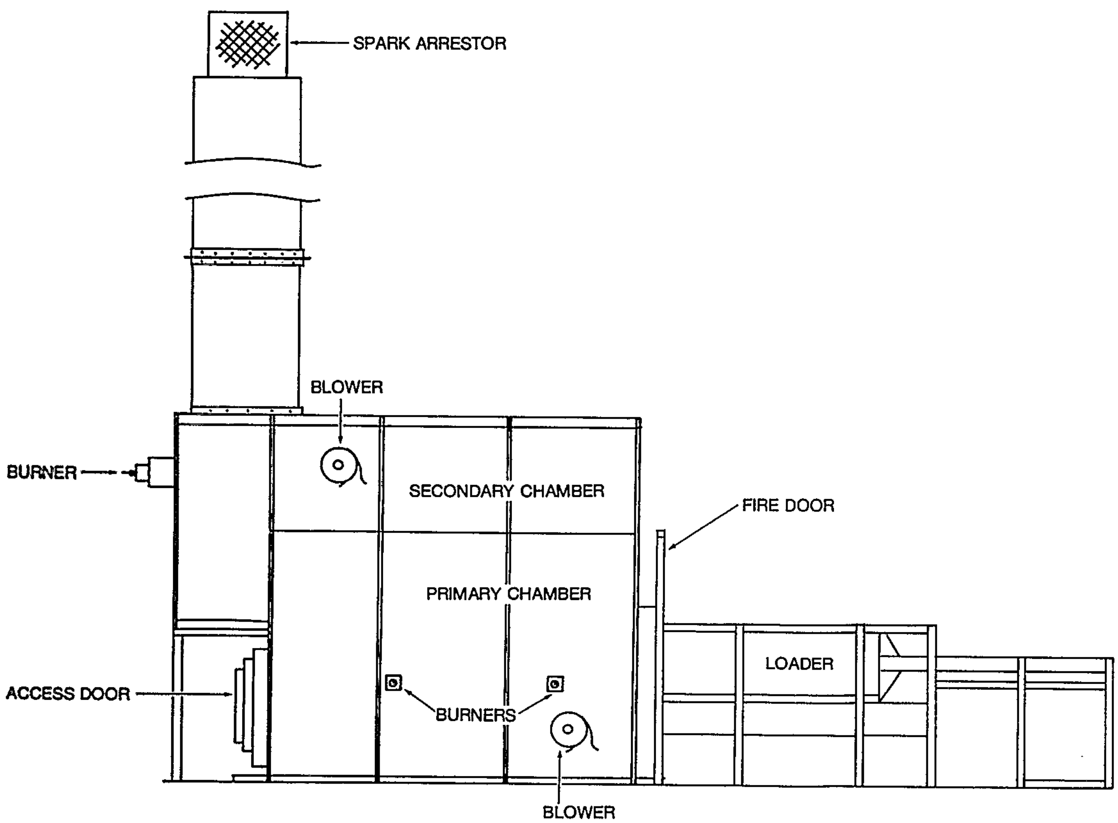


Figure 3. Configuration of two horizontal rectangular chambers with one above the other.

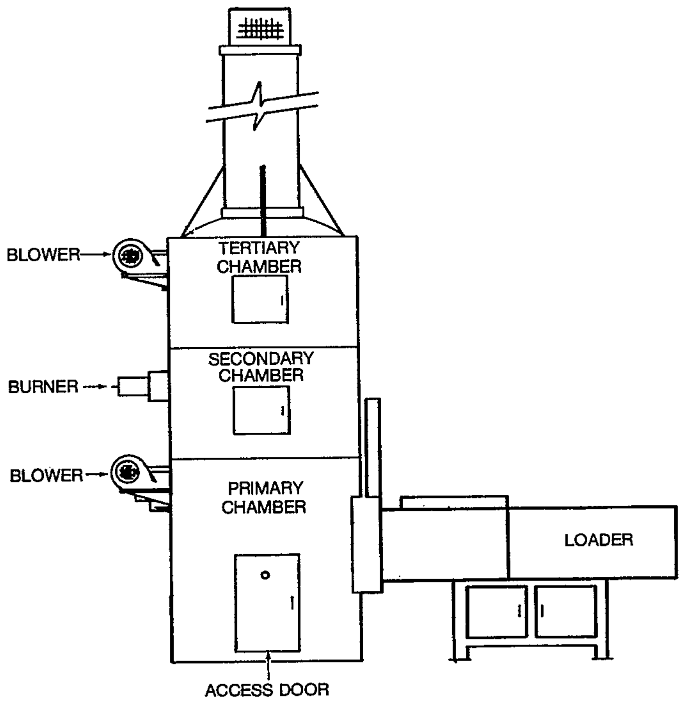


Figure 4. Configuration of Burn-Zol's two vertical cylindrical chambers with one above the other.

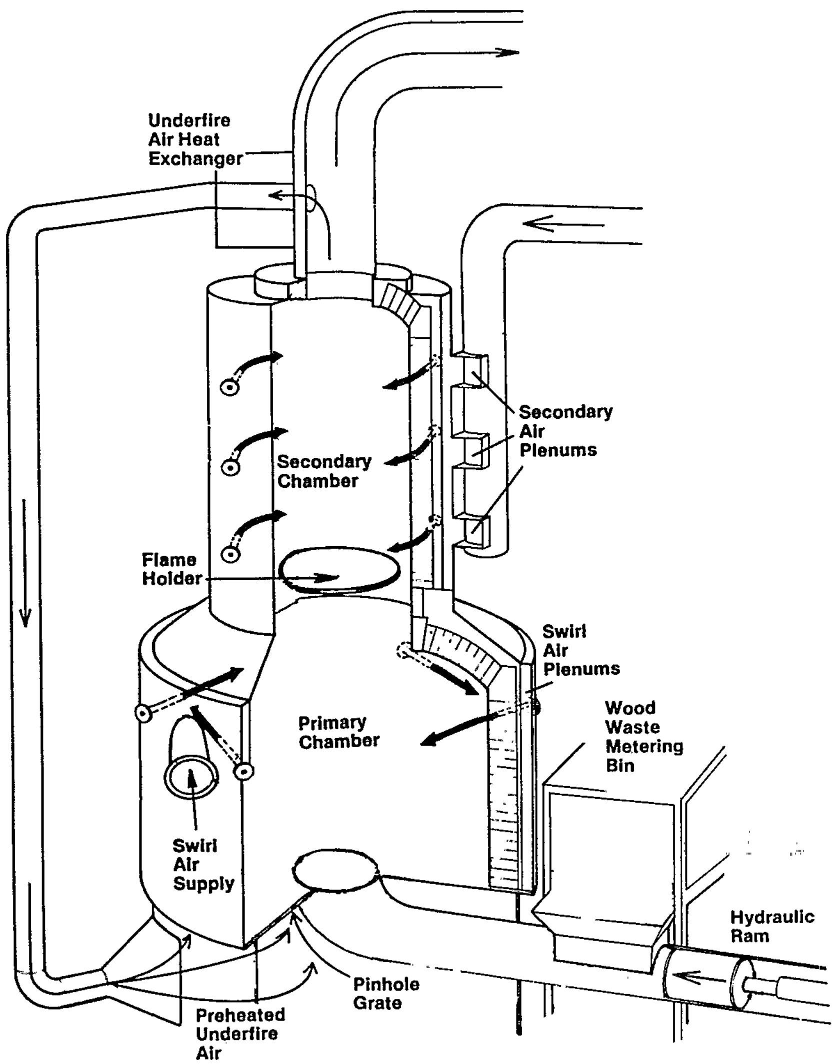


Figure 5. Configuration of Lamb-Cargate's two vertical cylindrical chambers with one above the other.

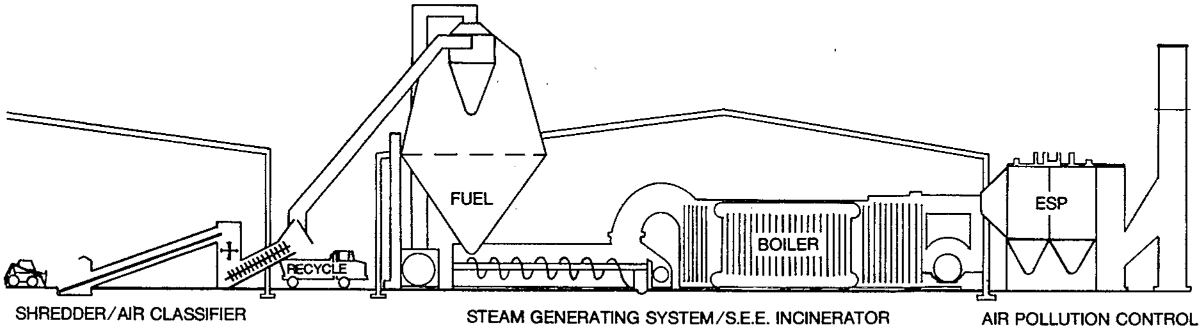


Figure 6. Configuration of Scientific Energy Engineering's incinerator with an auger in the primary chamber.

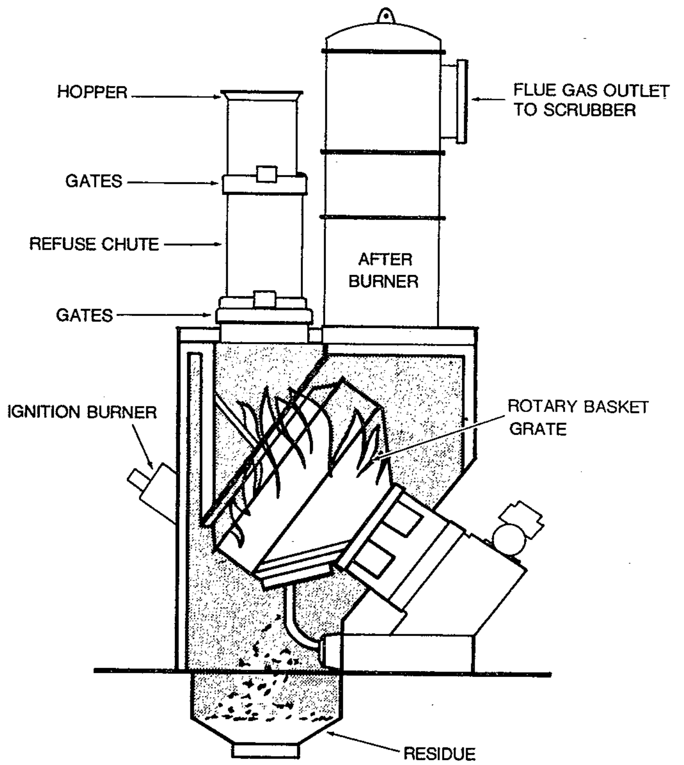


Figure 7. Configuration of Giery's incinerator with a rotary grate in the primary chamber.

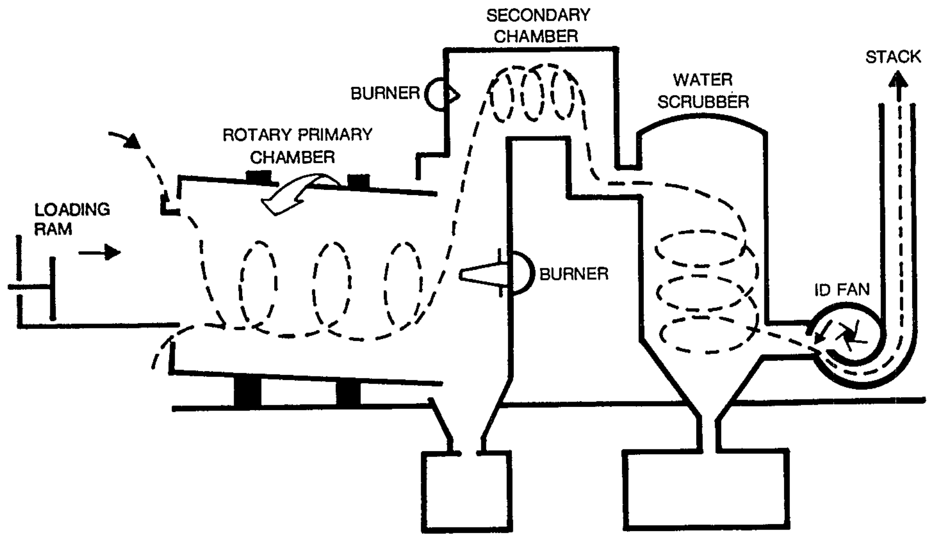


Figure 8. Configuration of C. E. Bartlett's incinerator with a rotary primary chamber.

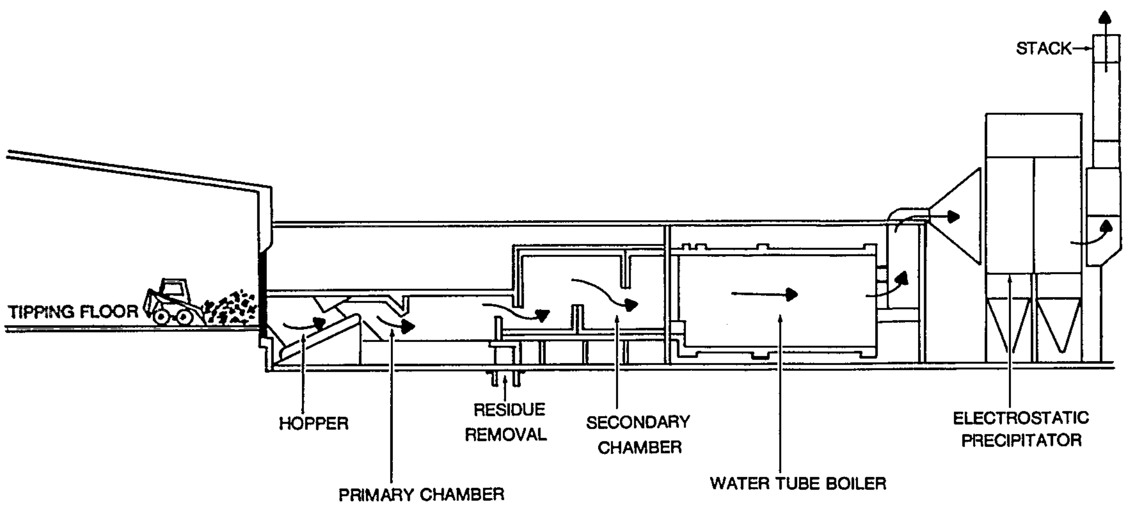


Figure 9. Configuration of Clear Air's incinerator-heat recovery system with two horizontal rectangular chambers aligned one after the other.

SECTION 3

OVERVIEW OF FACILITIES AND THEIR EVALUATIONS

EVALUATION OVERVIEW

The current program was designed to evaluate small modular incinerators in terms of operational data that would reflect the state-of-the-art of their technologies. Since incinerators burning municipal solid waste have different operating conditions than those burning industrial waste, a unit of each type was separately evaluated. Although the two evaluations are documented together, they are not compared since each typifies a discrete set of conditions. Consequently, the reader is cautioned against drawing any comparative conclusions.

The two selected facilities were each tested over three 1-week periods to gather data for technical, environmental, and economic evaluations. The technical evaluation consisted of (1) refuse and residue analyses, (2) efficiency analyses of the incinerator and the heat recovery boiler, (3) an operational data summary, and (4) a maintenance data summary. For each facility, a mass balance was prepared for the weekly field test with the most continuous and stable operating conditions to verify the accuracy of the data used in the energy efficiency and balance calculations. In the mass balance, the mass inputs to the system were calculated and compared with the measured mass outputs from the system. In the energy balance, the measured input energies were compared with the measured output energies. While the input and output values in each of these balances should be equal, values close to equality, i.e., less than a 5 percent difference between them, are normally considered the best achievable.

The environmental evaluation consisted of analyses of the stack flue gases, the residue, the process water, and the general plant environment. In addition, an EPA Level 1 type of anlysis was designed to identify the organic and inorganic elements in the system emissions. The EPA-recommended analysis methods and sampling techniques were applied to investigate the emissions that had a high potential for adversely affecting the environment. The economic evaluation consisted of capital cost, actual operational cost, and projected operational cost summaries.

NORTH LITTLE ROCK FACILITY

Description

The North Little Rock facility (referred to as the North Shore Energy Plant) is located in an industrial area of North Little Rock, Arkansas (see

Figure 10). During the time of this evaluation, the City was collecting, on the average, 63.4 Mg (70 tons) of solid waste per day. The estimated 1978 waste throughput of the North Shore Plant was 13,721 Mg (15,125 tons). Four Consumat Modular Model CS-1200 incinerators integrated with heat recovery equipment burn the waste and produce steam which is delivered under contract to the nearby Koppers Corporation, a manufacturer of creosote-treated wood products. The contract calls for an average 6804 kg (15,000 lb) per hour of steam at 150 psi to be delivered 24 hours per day, 5 days per week.

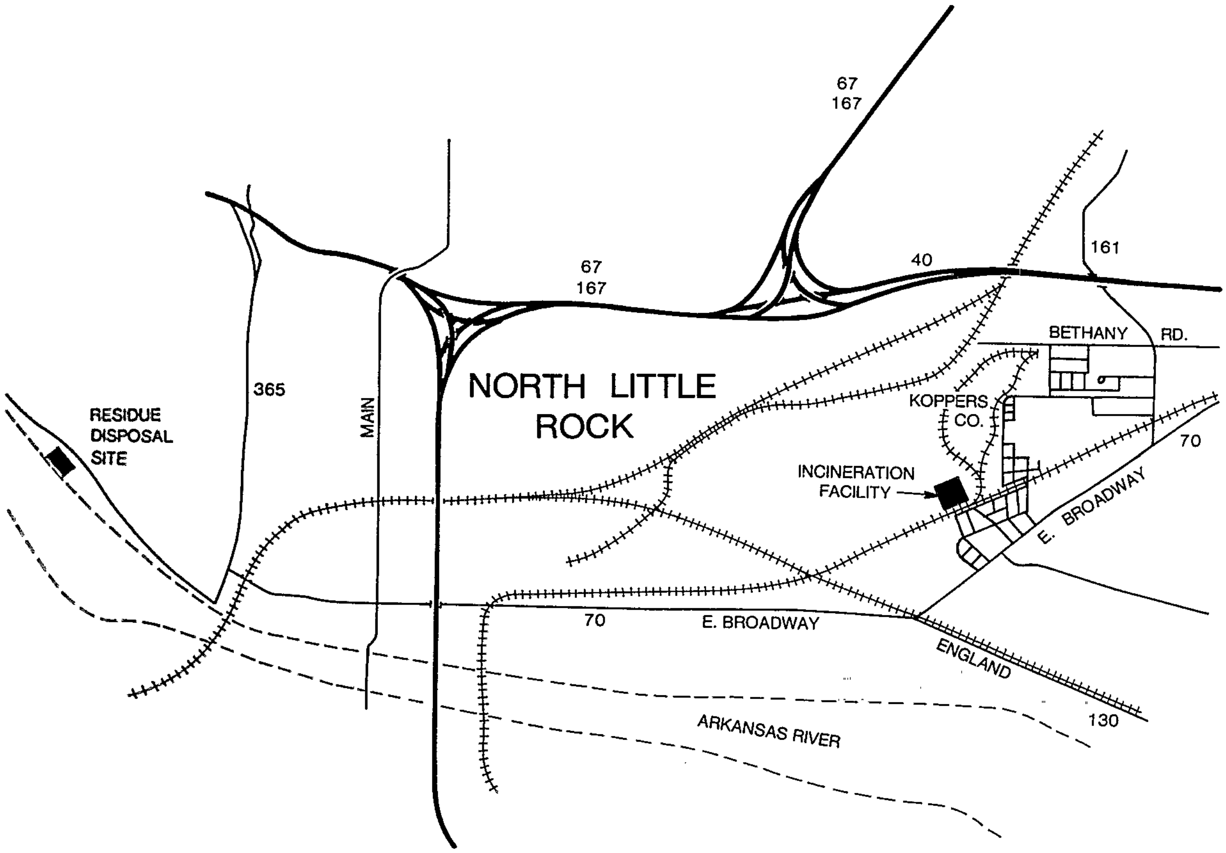


Figure 10. Vicinity map of North Little Rock facility.

The plant lies on a relatively flat, 8092-m^2 (2-acre) site adjacent to the Koppers plant. There are two structures on the site: a main building with a wing on each side, one facing east and the other west, and an administration building southwest of the main building and nearer to the plant access (see Figure 11).

The central part of the main building is the tipping floor, and each of the two wings contains an identical waste-to-heat energy module. Each module consists of (1) a dual loading ram; (2) a display panel for refuse loading instructions; (3) two control systems; (4) two identical incinerator systems each including a primary chamber with an automatic residue removal

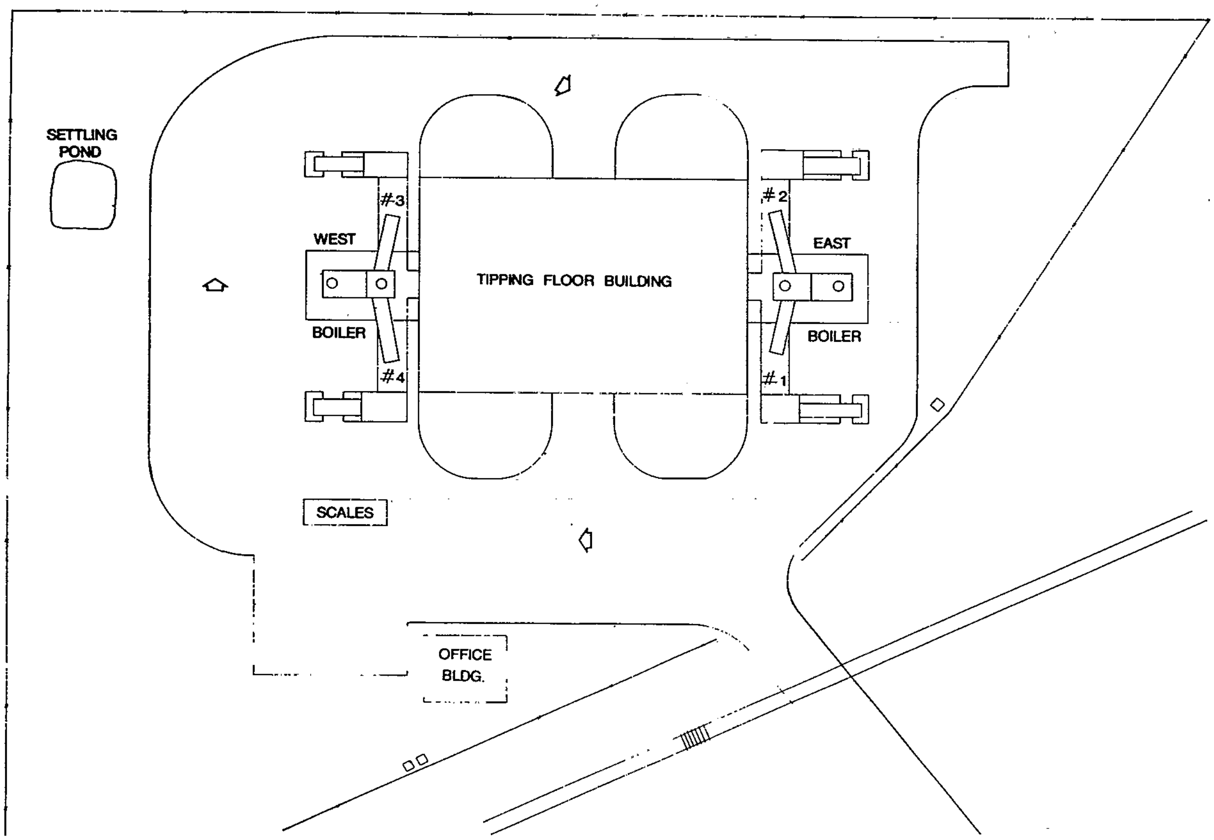


Figure 11. Plant layout of North Little Rock facility.

system and a secondary chamber; (5) a tee section with a dump stack common to the two incinerator systems; and (6) a heat recovery system that is common to both systems including a water tube boiler, a soot blower, a water treatment system, an aspirator section, and an exhaust stack (see Figure 12). Figure 13 shows the cross section of the system. The flow diagram of the process is shown in Figure 14.

Operation

Refuse Loading--

The operator of the skid-steer tractor on the tipping floor has the twofold task of pushing the truck-deposited refuse into each of the four floor corners for temporary storage and of pushing the piled waste along the loading platform to the hopper in both the east and the west waste-to-energy modules.

The load-size indicators on the loading display panel are automatically lighted according to the correlation of the primary chamber temperature with preset lower and upper limits. The three load sizes, namely, LOAD HEAVY, LOAD MEDIUM, and LOAD LIGHT, refer only to the quantity, that is, cubic

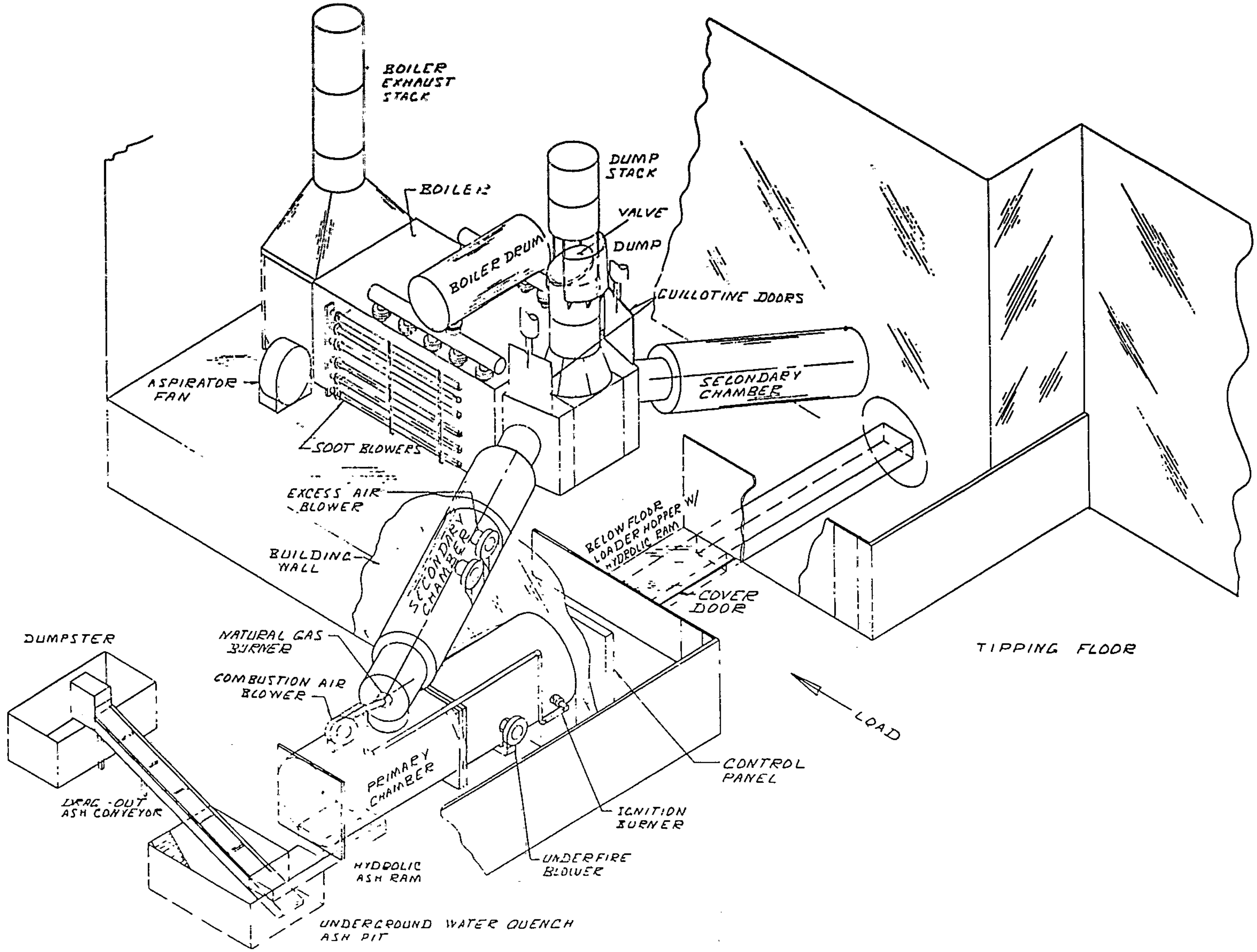


Figure 12. Three-dimensional drawing of incineration-heat recovery module in North Little Rock facility.

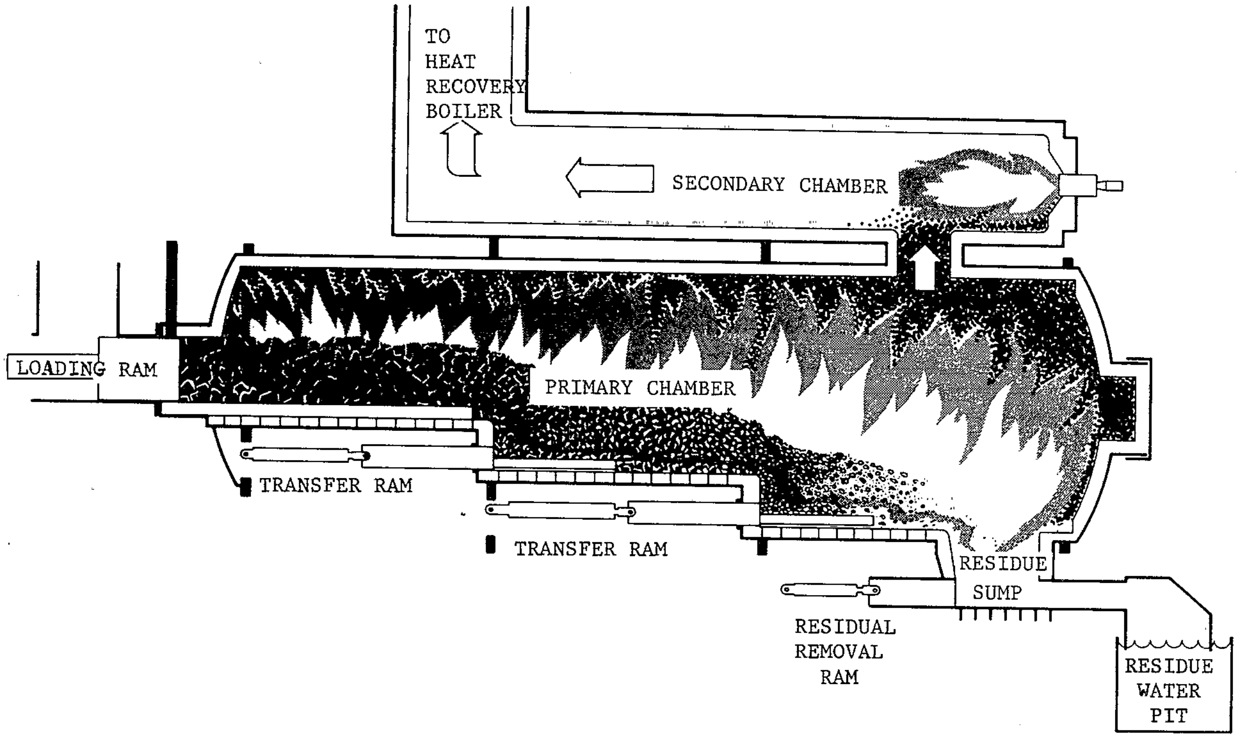


Figure 13. Cross section of incinerator module in North Little Rock facility.

yards of the refuse. Therefore, there is no need to vary the quality of the refuse gathered for any one of the three load sizes indicated. When the chamber temperature is above the high set point, the LOAD HEAVY frame, which represents the largest load, illuminates so that the next load will lower the temperature below the maximum level. When the chamber temperature is at the desired operating level, the LOAD MEDIUM frame, which represents the intermediate load, illuminates so that the next load will maintain the current temperature. When the chamber temperature is below the low set point, the LOAD LIGHT frame, which represents the smallest load, illuminates so that the next load will raise the temperature above the minimum level.

Steam Production--

The gases are slowly drawn through the heat exchanger by a negative pressure generated at the inlet side by the aspirator fan.

During steam production the cap at the base of the dump stack is pneumatically closed. Since the cap is normally held open by a counterweight as a fail-safe design, the flue gases are automatically discharged through the dump stack whenever the power fails, the flue gas control system malfunctions, the water in the steam drum or deaerator tank drops too low, or the steam generation rate exceeds the steam demand rate.

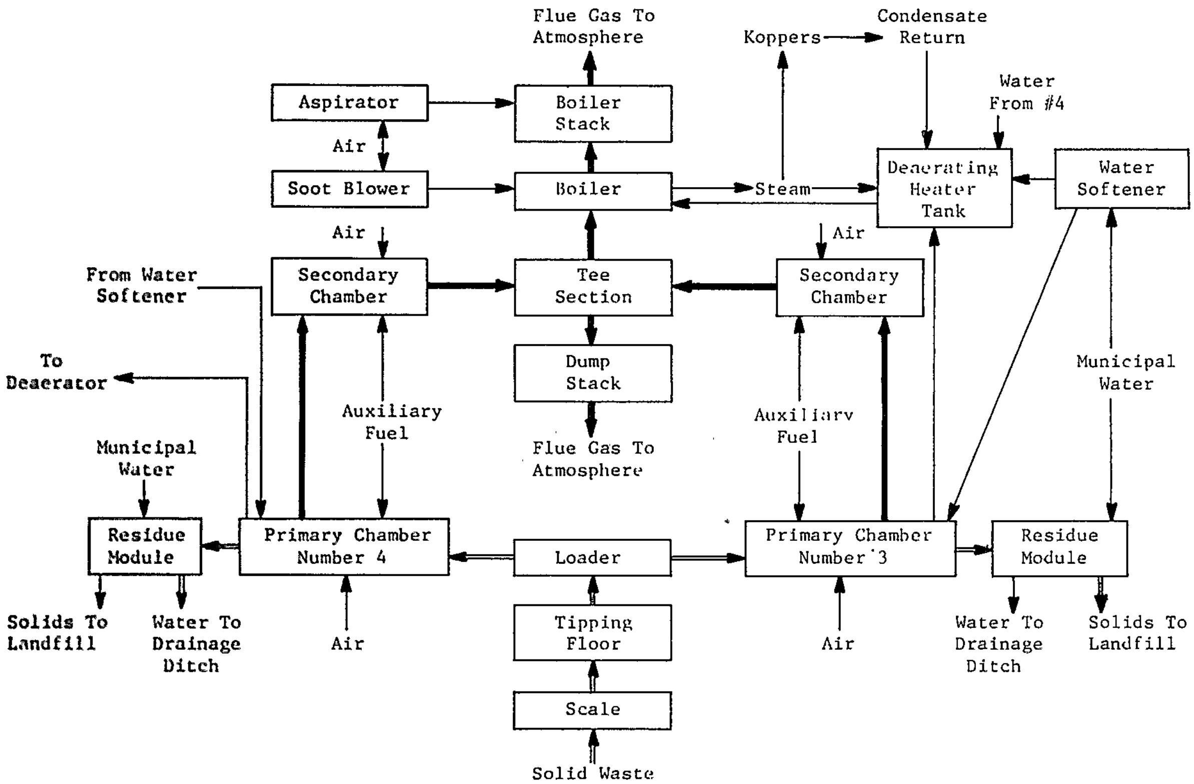


Figure 14. Flow diagram of incineration-heat recovery processes in North Little Rock facility.

Residue Transfer and Removal--

The two rams on the hearth of the primary chamber are cycled to push the residue forward and to break up clinker formations.

The residue removal ram is automatically cycled after several loading cycles. As the residue falls into the wet sump, it is sprayed with water. After a delay period the drag chain lifts the residue from the sump and deposits it into the residue removal container.

Introduction to Test Program

The purpose of the testing was to provide detailed data on the facility performance. Since both wings of the plant are identical and operate under the same conditions, only one set of incinerators and the common steam module were tested. The system in the west wing was chosen.

The facility was tested for 1-week periods during the months of March, May, and October 1978. Of the three tests, the October test had the most continuous and stable operating conditions. The data for this test, therefore, were used in the technical evaluation of the facility.

The October test began at normal start-up Sunday night and lasted for 118.5 hours to late Friday night when burndown began. During that period, 204,300 kg (450,000 lb) of refuse were burned at an average weekly rate of 1725 kg/hr (3800 lb/hr) and at a daily rate ranging from 1634 to 1770 kg/hr (3600 to 3900 lb/hr) in the two incinerators being monitored.

Technical Evaluation

As indicated by Table 3, which summarizes the refuse weights and sorts in 11 categories, the incinerator handled a wide variety of refuse sizes and components. However, the operator manually removed large, bulky, explosive, metallic, and wire objects before the refuse was dumped into the loading hopper.

During the three field tests, the refuse had a moisture content varying from 22 to 35 percent and an average bulk density of 97.7 kg/m^3 (165 lb/yd^3). The residue had an average bulk density of 896 kg/m^3 (1510 lb/yd^3) with 69 percent of the residue particles being smaller than 1 inch. The refuse reduction through combustion was 55 percent by weight and 95 percent by volume based on the ratio of wet residue to as-received refuse. On a dry residue basis, the refuse weight reduction was 70 percent.

The weekly system mass balance for the October field test compares the mass flows entering and leaving the incinerator-heat recovery system. While the system inputs measured were the refuse, the combustion air, the auxiliary gas, the residue cooling water, and the aspirator fan air, the system outputs measured were the residue and the boiler exhaust stack flue gas. Figure 15 presents the mass balance on a per ton input basis. Over the 118.5-hour test, the total mass input was 4127 Mg (4550 tons) and the mass output was 4199 Mg (4629 tons). The difference, namely 71.7 Mg (79 tons) or 2 percent of the output, was not accounted for.

The energy balance in Figure 16 compares the measured energy inputs and outputs on a per ton input basis. For this balance, the inputs were refuse, electricity, and auxiliary fuel while the outputs were steam, sensible heat and remaining energy in the residue, heat lost by radiation and convection, and sensible heat in the flue gases. The energy inputs and outputs on the 118.5-hour test totaled 2298 and 2350 GJ (2178 and 2228 MBTU), respectively. The lesser energy output of 52 GJ (50 MBtu) or 2 percent of the energy input, was well within the expected ±5 percent closure.

Each of the two Consumat heat recovery modules was designed to produce 4,540 kg (10,000 lb) of steam per hour. The total plant steam demand, as measured by a Honeywell steam flow integrator, averaged 4,994 kg (11,000 lb) per hour with a maximum and minimum of 6,356 and 2,724 kg (14,000 and 6,000 lb) per hour. On the average, the plant steam demand was 79 percent of the original anticipated demand of 6,810 kg (15,000 lb) per hour. The west-end waste-to-energy module (the module tested) had steam ouputs that averaged 3,746 kg (8,250 lb) per hour and reached levels between 4,994 and 5,357 kg (11,000 and 11,800 lb) per hour during peak demand periods that lasted from

Table 3. NORTH LITTLE ROCK WEEKLY REFUSE COMPOSITION FOR MARCH, MAY, AND OCTOBER TESTS

Category	March		May		October	
	Weekly % by weight	Category weight kg(lb)	Weekly % by weight	Category weight kg(lb)	Weekly % by weight	Category weight kg(lb)
Food waste	8.8	13,104(28,890)	6.7	10,332(22,779)	6.8	13,880(30,600)
Garden	7.2	10,722(23,638)	4.2	6,477(14,279)	3.0	6,123(13,500)
Paper	48.1	71,692(157,914)	49.6	76,489(168,630)	54.1	110,019(242,550)
Plastic	6.1	9,084(20,027)	7.4	11,412(25,159)	8.7	17,758(39,150)
Textiles	3.4	5,063(11,162)	1.5	2,313(5,100)	2.2	4,491(9,900)
Wood	1.4	2,085(4,596)	1.1	1,696(3,740)	1.0	2,041(4,500)
Ferrous	8.3	12,360(27,249)	9.8	15,113(33,318)	8.8	17,962(39,600)
Aluminum	1.1	1,638(3,611)	1.8	2,776(6,120)	3.2	6,532(14,400)
Glass	10.9	16,232(35,785)	11.8	18,197(40,118)	7.6	15,513(34,200)
Inert	1.6	2,383(5,253)	0.4	617(1,360)	0.3	612(1,350)
Fines	3.2	4,765(10,506)	5.7	8,791(19,380)	4.1	8,369(18,450)
Total#	100.1	149,198(328,631)	100.0	154,350(339,980)	99.8	203,483(448,200)

\# Totals do not equal weighed refuse total due to rounding and averaging.

30 to 60 minutes. The pressure in the steam drum varied from 120 psi at peak demands, to 130 psi at the average steam demand, and to a high of 140 psi at the low steam demand. The efficiency of the refuse combustion was 94 percent, or 6 percent of the combustibles were unburned and removed with the residue.

The system energy efficiencies, as calculated by the input-output, and the heat loss methods were 56 and 54 percent, respectively. Because of the high moisture and hydrogen content of the refuse, the net efficiency of the system was calculated with a net heating value to eliminate the heat lost by evaporating the moisture. The resultant 65 percent efficiency was 9 to 11 percent higher than the efficiency computed with the total or as-received heating value.

The operation of the facility required a total of nine personnel, i.e., one supervisor, one office manager, one truck driver, and two operators per shift for each of the three shifts. The supervisor position was critical to the successful operation of the plant. The office manager maintained all plant records such as those for utilities, refuse delivery, and steam consumption. The truck driver transported the residue to the disposal site.

Mass balance 118.5-hour test*

Source	Input: Mg per Mg refuse or Ton per ton refuse	Input: % of Total	Output: Mg per Mg refuse or Ton per ton refuse	Output: % of Total
Refuse	1.0	4.92		
Natural gas	0.002	0.01		
Residue, cooling water	0.157	0.77		
Aspirator air	10.26	50.54		
Blower air	8.88	43.76		
Residue, wet			0.45	2.19
Flue gases			20.13	97.81
Total	20.299	100.00	20.58	100.00

* Total refuse input 204 Mg (225 tons).

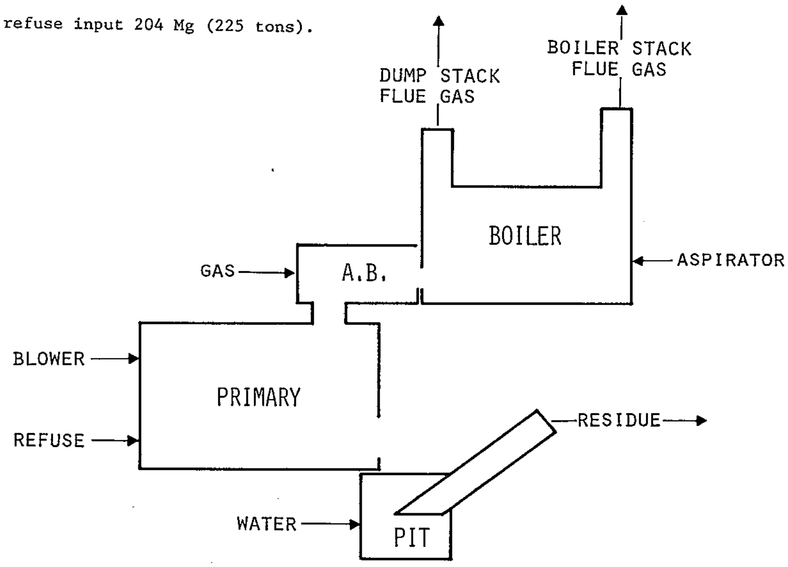


Figure 15. Mass balance for incineration-heat recovery processes in North Little Rock facility during the 118.5-hour October field test.

Energy balance 118.5-hour test *

Source	Input			Output		
	GJ per Mg of refuse	(MBtu per Ton of refuse)	% of total	GJ per Mg of refuse	(MBtu per Ton of refuse)	% of total
Refuse	11.12	(9.56)	98.71			
Electricity	.09	(.08)	0.83			
Natural gas	.052	(.044)	0.46			
Unburned combustibles				.661	(.569)	5.74
Steam				5.99	(5.15)	52.05
Flue gases				4.30	(3.70)	37.36
Radiation and Convection				0.56	(0.48)	4.85
Total	11.262	(9.684)	100.00	11.51	(9.909)	100.00

***Total refuse input 204 Mg (225 ton)**

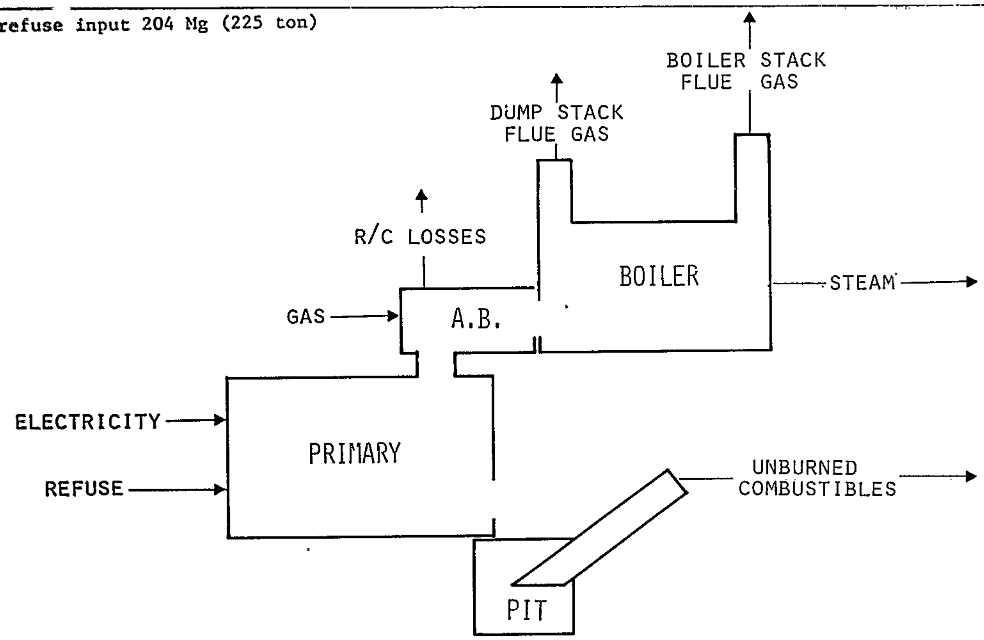
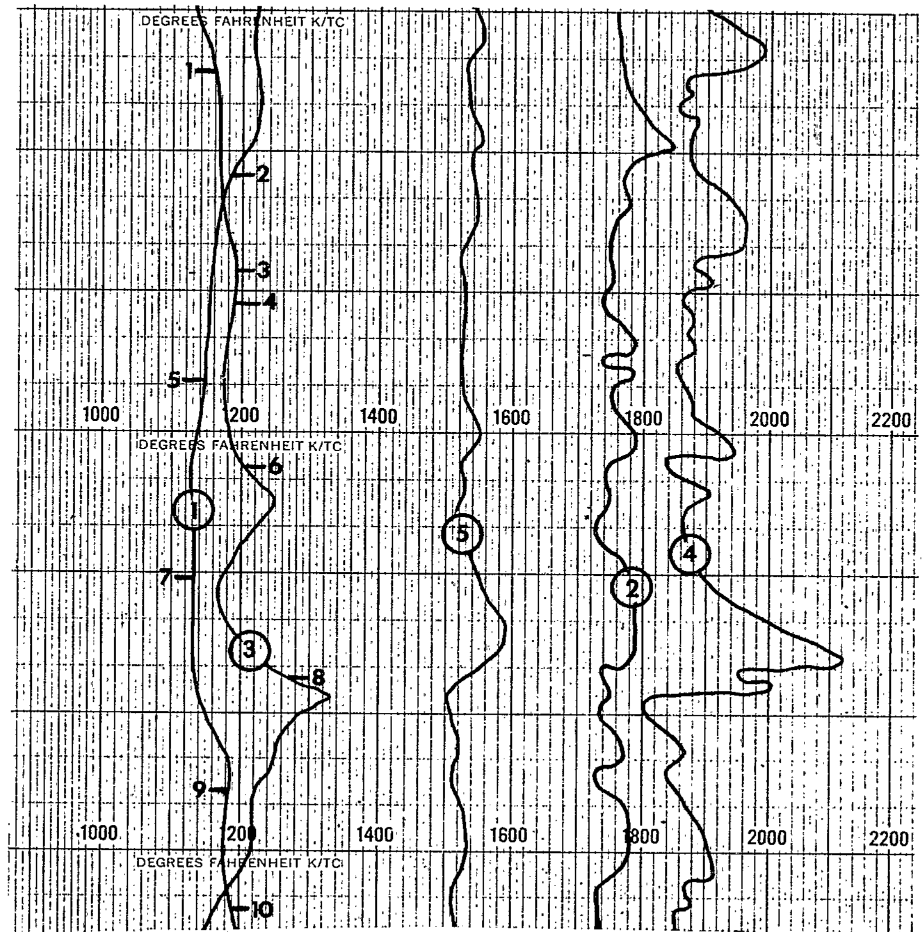


Figure 16. Energy balance for incineration-heat recovery processes in North Little Rock facility during the 118.5-hour October field test.

The two operators shared routine maintenance and incinerator loading operations. The steady-state, efficient operation of the system requires that the operators closely follow the start-up procedures, the automatic loading instructions, and the burndown procedures. The effects on the system temperatures and gaseous emissions when the hopper loads varied from light to heavy are shown in Figures 17 and 18.



LEGEND
① Temperature in Primary Chamber No. 3.
② Temperature in Secondary Chamber No. 3.
③ Temperature in Primary Chamber No. 4.
④ Temperature in Secondary Chamber No. 4.
⑤ Temperature at Boiler Entrance.

EVENTS

1. Load, light No. 4
2. Load, light No. 3
3. Load, medium No. 4
4. Residue dump No. 4
5. Load, light No. 3
6. Load, medium No. 4
7. Load, light No. 3
8. Load, medium No. 4
9. Load, medium No. 3
10. Load, medium No. 4

Figure 17. System temperature versus loading sizes and events in North Little Rock facility.

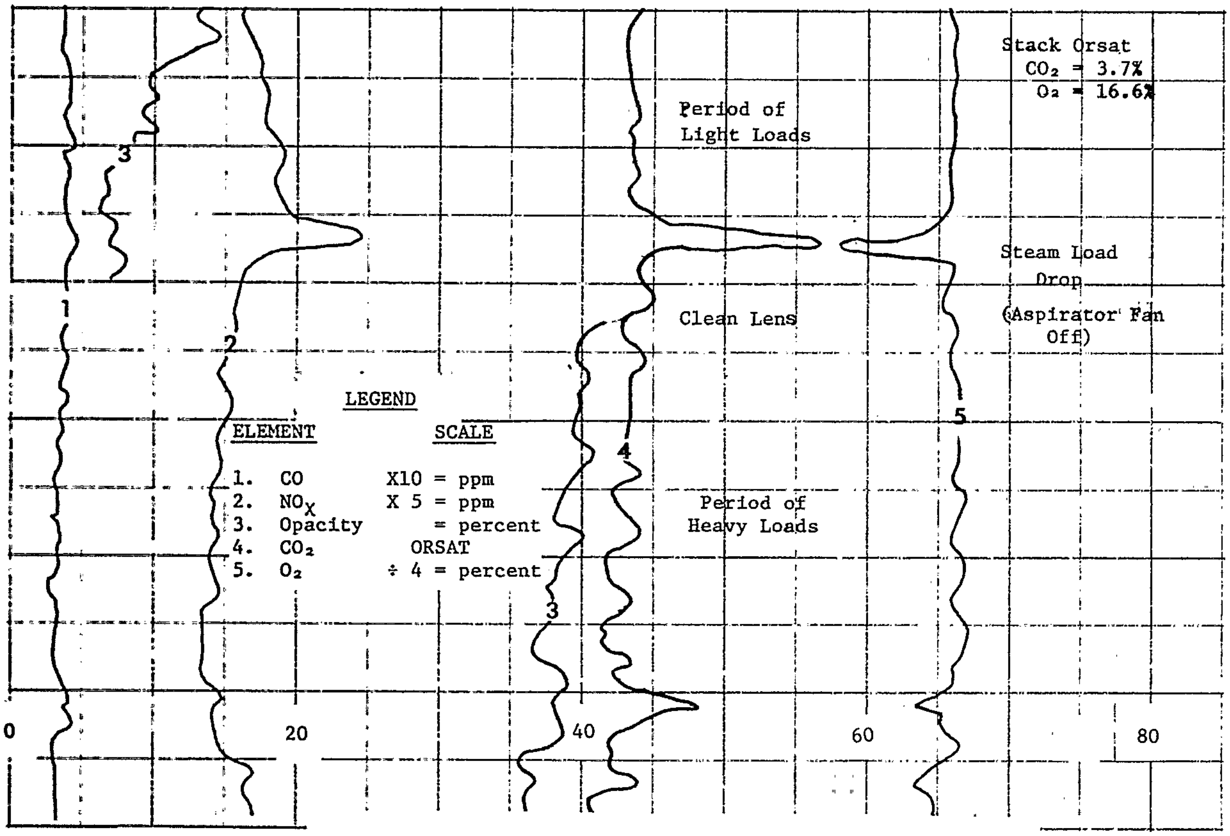


Figure 18. Stack emission during heavy and light loading periods in North Little Rock facility.

The routine maintenance of the facility required a working knowledge of the hydraulic, electronic, and mechanical systems. A supply of small spare parts, such as switches, thermocouples, hydraulic parts, and motors, was essential for continuous 24-hour operation. While major maintenance during the week required shutting down the incinerator, much maintenance could be performed during an hour or two with the incinerator still operating but at reduced capacity. Normally, the major maintenance (if required) and removal of soot deposits in the boiler were performed during the weekend.

Environmental Evaluation

For the October test, Table 4 presents the flue gas emissions in terms of grains per standard cubic foot (gr/SCF) and grams per standard cubic meter (g/SCM) and pounds per ton of refuse processed. Table 5 summarizes the emissions for each of the three test periods. The size distribution analysis of the particulates during the October test revealed that 95 percent by weight of the particulates were smaller than 7 μm and 50 percent by weight were 0.3 μm or less. In five October tests for total particulates, including the wet-catch particulates, the total particulates, corrected to 12 percent CO_2 averaged 0.397 g/SCM (0.174 gr/DSCF) with a maximum of 0.500 g/SCM (0.219 gr/DSCF) and with a minimum of .271 g/SCM (0.119 gr/DSCF). While the concentrations of chloride ranged from 19 to 610 mg/m^3 (13 to 420 ppm) and averaged 187 mg/m^3 (130 ppm), those of fluoride ranged from 0.5 to 4.3 mg/m^3 (0.6 to 5.5 ppm) and averaged 1.6 mg/m^3 (2.0 ppm) over the three test periods.

TABLE 4. NORTH LITTLE ROCK POLLUTANT EMISSION RATES FOR OCTOBER TEST

	Emission rate			
Pollutant	Maximum	Average	Minimum	lb/ton refuse charged†
Particulate	.231* gr/SCF	.130* gr/SCF	.067* gr/SCF	3.03
SO_x		<10 ppm		<0.78
NO_x	99 ppm	82 ppm	69 ppm	3.68
CO	36 ppm	29 ppm	16 ppm	1.00
HC	40 ppm	28 ppm	20 ppm	0.55
Pb		4.49 mg/m^3		0.14

* Corrected to 12 percent CO_2.
† Based on an average flow of 15,198 DSCFM including aspirator air and a feed rate of 1.9 TPH.

TABLE 5. NORTH LITTLE ROCK SUMMARY OF STACK EMISSION FOR MARCH, MAY, AND OCTOBER TESTS

	Field test											
	Test 1: March 3-20, 1978				Test 2: May 5-22, 1978				Test 3: October 9-13, 1978			
Emissions (units)	Max	Avg	Min	Std Dev	Max	Avg	Min	Std Dev	Max	Avg	Min	Std Dev
Particulate (gr/SCF)*	.1847	.1430	.0998	.0282	.2779	.1906	.0747	.0545	.2312	.1297	.0669	.0549
Particulate (g/m^3)*	.4227	.3458	.2284	.0682	.6359	.4609	.1709	.1318	.5291	.3136	.1531	.1327
Chlorides (mg/m^3)	609.9	344.7	217.0	126.8	34.9	26.0	19.4	6.0	193.3	154.8	127.4	24.2
Fluorides (mg/m^3)	4.3	2.3	1.6	1.0	1.7	1.3	.6	.5	1.2	.9	.5	.5
Stack O_2 (percent)	18.3	17.2	16.5	.8	19.0	17.1	15.1	.9	18.0	16.9	13.8	.8
Stack CO_2 (percent)†	3.5	3.1	2.8	.3	4.5	2.6	1.9	.7	4.7	4.1	3.5	.4
Stack CO_2 (percent)††		No Data				No Data			6.8	4.4	2.6	.9
Stack CO (mg/m^3)		No Data			61.4	35.2	16.6	9.4	46.4	21.6	<11.0	15.8
Stack NO_x (mg/m^3)	112.8	102.3	95.6	7.2	175.0	94.8	<10.0	39.8	213.9	129.7	57.3	38.1
Stack SO_x (mg/m^3)	13.3	13.3	13.3	0	33.3	10.3	<13.0	9.4	<13.0	<13.0	<13.0	0
Stack H_2O (percent by volume)	6.7	6.0	4.5	--	9.7	7.9	6.8	--	7.5	6.1	4.2	--
Boiler O_2 (percent)	--	11.6	--	--	14.5	11.5	9.2	1.7	12.6	10.7	8.8	.5
Boiler CO_2 (percent)††		No Data				No Data			11.6	9.5	7.5	.6
Boiler CO (mg/m^3)		No Data			61.7	44.6	25.8	10.4	91.6	37.4	<11.0	22.9
Boiler NO_x (mg/m^3)	334.3	272.2	181.5	56.3	510.0	284.4	76.6	114.4	450.8	386.9	192.9	58.4
Boiler SO_x (mg/m^3)	133.3	56.5	13.3	49.2	88.0	22.5	<13.0	19.4	26.6	3.3	<13.0	6.2
Particulate size (μm)#	34.0	3.0	<0.3	--	28.0	0.3	<0.3	--	28.0	0.3	<0.3	--
Hydrocarbons (mg/m^3)ϕ	0.19	0.16	0.15	--	0.19	0.12	0.06	--	25.3	1.78	1.26	--
Opacity (percent)		No Data				No Data			42	24	12	--
Flue gas temperature (°F)	259	249	234	--	260	242	217	--	289	285	274	--
Flue gas flow (SCFM)	19,313	15,671	13,975	--	18,883	15,822	12,260	--	18,658	16,185	15,192	--
Flue gas flow (CFM)	26,166	21,085	18,436	--	26,084	22,893	17,518		26,207	22,823	21,484	

* Corrected to 12 percent CO_2
† Data from Orsat analyser
\# Average is mass mean diameter
ϕ Average of CH_4-C_4H_{10}
†† Continuous NDIR monitor

The mechanical functions and the operational procedures were investigated to determine their effect on the particulate emission level. Within the scope of the available data, the emission level increased whenever the temperature in the primary chamber, the size of the charging load, or the amount of underfired air increased. The individual effects of these parameters could not be determined because of their interrelationships in the system. The particulate emission level could not be correlated with the following: excess air amounts, secondary chamber temperature, residue ram action, aspirator fan flow rate, and the waste characteristics.

The plant was designed to meet a state-imposed particulate standard of 0.2 gr/DSCF corrected to 12 percent CO_2. The present federal standard for municipal incinerators with capacities greater than 50 TPD is 0.08 gr/DSCF corrected to 12 percent CO_2. However, this standard does not apply to the North Little Rock facility because each pair of incinerator units is rated at less than 50 TPD. Since the facility complied with the emissions limitation prescribed in its permit, the reader is cautioned against assuming that the North Little Rock facility did not comply with the federal standard.

A similar unit in Salem, Virginia, was designed to meet a state-imposed standard of 0.08 gr/DSCF corrected to 12 percent CO_2. As of the date of this publication (September 1979), this small modular system (with automatic feed and ash removal) has not demonstrated its capability of meeting the state air emission standards.

The daily discharge of process water varied from 37.85 to 113.5 m^3 (10,000 to 30,000 gallons). Of the significant discharge water characteristics, the tipping floor water had a BOD of 1780 mg/ℓ, a COD of 2710 mg/ℓ, and an arsenic level of 9 mg/ℓ; and the residue removal sump water had a pH of 12 and a temperature of 39° C. The tipping floor water is treated by a municipal treatment plant. Concentrations of the pollutants are not high enough to affect the treatment plant's operation.

The residue contained unburned hydrocarbons and traces of a wide range of heavy metals. The tests on the laboratory-produced leachate, as summarized in Table 6, revealed insignificant amounts of pollutants. This finding was due primarily to high pH levels that restricted the solubility of the heavy metals in the leachate. Although the laboratory-tested residue and leachate had insignificant amounts of pollutants, the residue could be a source of pollution if its pH level dropped enough to allow the solubility of the residue heavy metals during the surface drainage at the local site and/or the leachate formation at the disposal site.

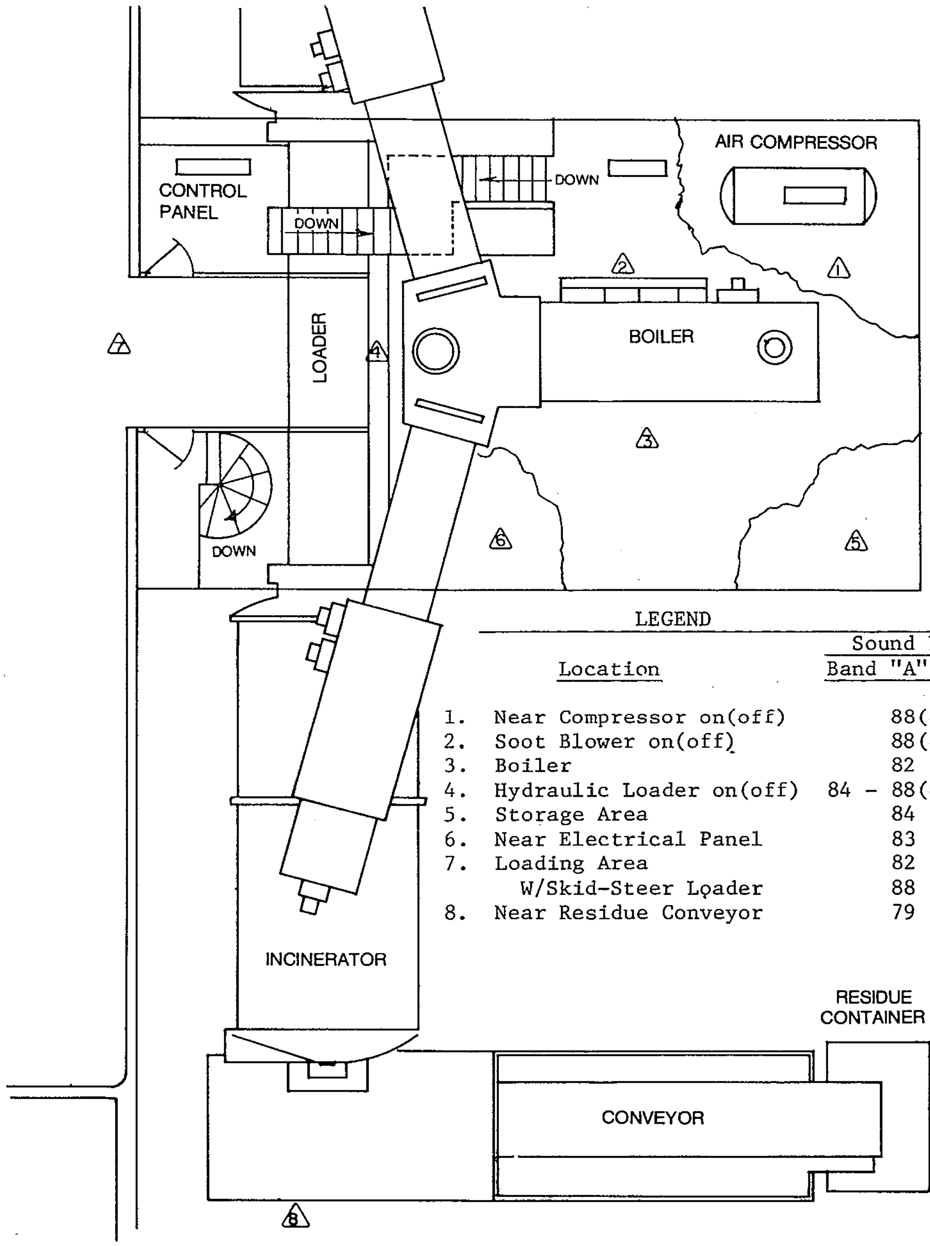
Within the facility building, the levels and the viable microorganism content of the fugitive dust were low, and the noise levels never exceeded the OSHA limits (see Figure 19).

Outside the building no significant amounts of pollutants were found at the upwind or downwind ambient air sample sites; both sites were at a 91.4-meter (300-foot) distance from the boiler exhaust stack. The noise levels were within standard limits (see Figure 20).

TABLE 6. NORTH LITTLE ROCK RESIDUE LEACHATE PARAMETER AND COMPONENT VALUES

		Water Blank	Test 1	Phosphate Buffer Test 2
pH		5.52	8.65	6.05
Conductivity	umhos	2.78	185.00	2800
Alkalinity	mg/l	1.10	43.50	144
TKN	mg/l	6.95	5.25	11.6
Hardness	mg/l	2.00	70.00	ND
TOC	mg/l	3.10	5.70	2.2
Ortho-Phosphate	mg/l	0.005	0.025	1400
Total Phosphate	mg/l	0.01	0.044	1975
Sulfide	mg/l	<0.002	0.002	ND
Chloride	mg/l	ND	0.71	12
Acidity	mg/l	5	ND	1841
Total Dissolved Solids	mg/l	<1	80	5770
Ammonia as N	mg/l	0.216	0.183	0.23
COD		ND	ND	ND
Sulfate	mg/l	<1.00	34.30	16.6
Bromide	mg/l	<0.100	<0.100	1.0
Fluoride	mg/l	0.058	0.099	.07
Boron	mg/l	<0.1	<0.1	.127
Mercury	µg/l	<0.1	<0.1	–
Cadmium	µg/l	<1	<1	–
Antimony	µg/l	<1.0	5.4	–
Lead	µg/l	<1	<1	–
Chromium	µg/l	<1	<1	–
Arsenic	µg/l	ND	ND	–
Cyanide	mg/l	–	–	< .002
Phenols	mg/l	–	–	.005
MBAS	mg/l	–	–	0.12
Sulfur	mg/l	–	–	–

ND = None detected



LEGEND

Location	Sound Level Band "A" dB	Sound Level Imp
1. Near Compressor on(off)	88(84)	105
2. Soot Blower on(off)	88(87)	100
3. Boiler	82	94
4. Hydraulic Loader on(off)	84 - 88(81)	
5. Storage Area	84	
6. Near Electrical Panel	83	
7. Loading Area	82	
W/Skid-Steer Loader	88	
8. Near Residue Conveyor	79	93

Figure 19. In-plant noise-level plot for North Little Rock facility.

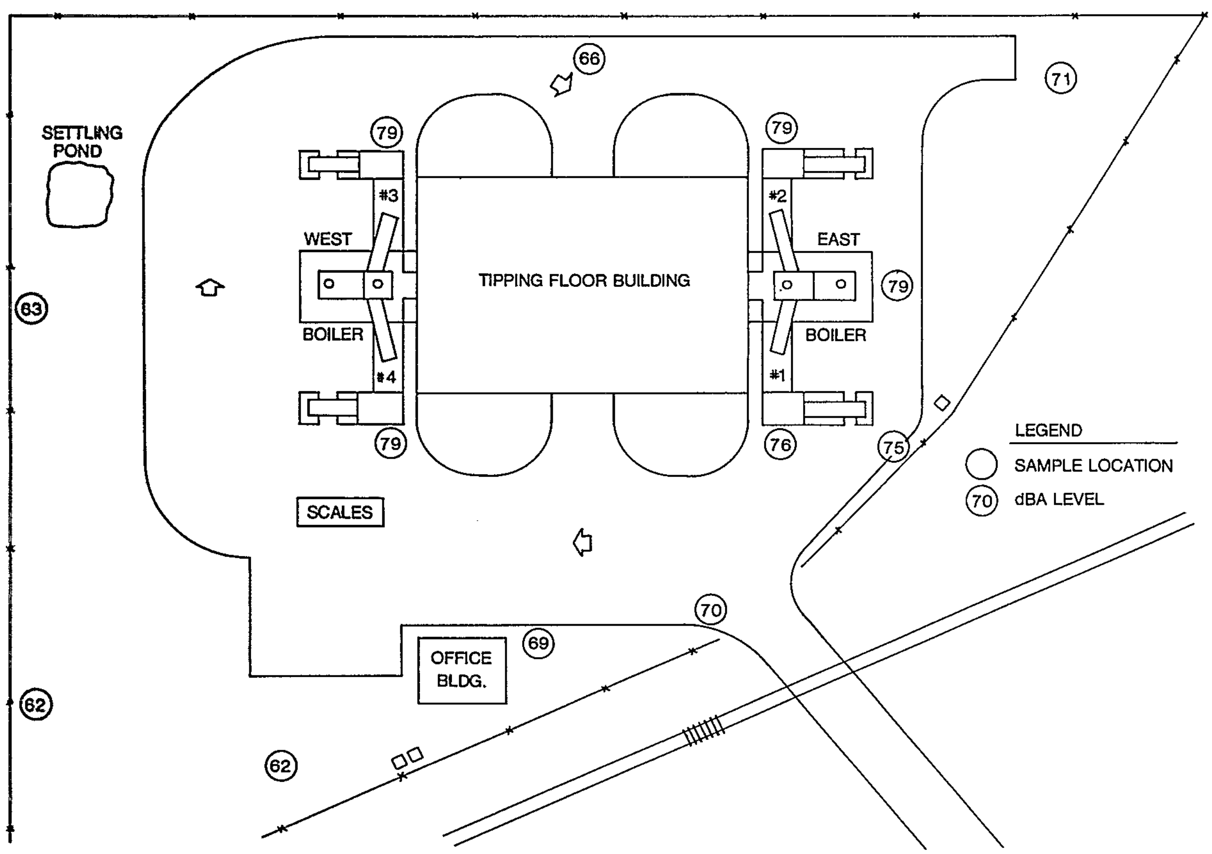


Figure 20. Outside-plant noise-level plot for North Little Rock facility.

The major elements detected in the EPA Level 1 analysis are shown in Table 7. Other metals and elements were found occasionally in smaller amounts.

TABLE 7. NORTH LITTLE ROCK SUMMARY OF ELEMENTS DETECTED IN STACK EMISSION FILTERS

Element	Emission rate: Concentration in gas (μg/m³)*	Emission rate: Emission factor g/Mg of refuse†
Silicon	3.22	.0505
Iron	261.	4.10
Aluminum	331.	5.20
Sodium	9,363.	147.0
Calcium	894.	14.0
Potassium	381.	5.98
Magnesium	331.	5.20
Lead	4,280.	67.2
Zinc	9,071.	142.
Cadmium	123.	1.93
Beryllium	0.114	.0018
Titanium	.333	.0052
Chromium	1.105	.0173
Copper	62.57	.982
Nickel	1.97	.031
Manganese	8.02	.126
Lithium	2.48	.039
Antimony	13.26	.208
Boron	105.0	1.640
Tin	3.81	.0598
Vanadium	2.26	.0354

* Concentrations based on a composite of six filters from October test period.

† g/Mg ÷ 500 = lb/ton

Economic Evaluation

The total cost of the plant in 1977 was $1,529,404. Table 8 presents the total capital cost breakdown by EPA cost categories, and Table 9 presents the unit operational cost. These costs are based on averages of the actual unit costs over the evaluation period. Table 10 presents the projected annual operating and maintenance costs based on the as-operating parameters; i.e., feed rate and steam capacity equal to 2.72 Mg (3 tons) and 7274 kg (16,000 lb) per hour, respectively.

Table 11 presents the estimated annual revenues. The as-operated economic and production conditions yield a total revenue and a revenue per Mg of refuse processed that are respectively $177,335 and $10.94.

TABLE 8. NORTH LITTLE ROCK ACTUAL CAPITAL COSTS*

Land	$ 10,000
Site preparation	101,093
Design	37,583
Construction	311,383
Real equipment	968,929
Other equipment	62,886
Other costs	37,530
Total capital investment	$1,529,404

*Based on actual costs in 1977.

TABLE 9. NORTH LITTLE ROCK UNIT COST DATA*

Annual salary rates:	
Director of sanitation	$19,000
Plant superintendent	13,290
Maintenance superintendent	10,800
Operator	9,442
Truck driver	8,086
Secretary	7,956
Overtime	5,000
Employee benefits:	
Health insurance (each employee)	$29.70/month
Retirement	5.00%
FICA	6.05%
Fuel rates:	
Natural gas	$0.056/1000 ℓ
Number 2 diesel oil	$0.122/ℓ
Gasoline	$0.140/ℓ
Electricity:	$0.034/kwh
Water and sewer:	$0.0918/1000 ℓ

*Based on cost projections from costs incurred during September 1978.

TABLE 10. NORTH LITTLE ROCK PROJECTED ANNUAL OPERATING AND MAINTENANCE COSTS*

Item	Cost ($/yr)	Cost ($/Mg)
Salaries	$111,284	$ 6.87
Employee benefits	15,750	0.97
Fuel - no. 2 diesel	3,456	0.21
Natural gas	16,704	1.03
Gasoline	2,916	0.18
Electricity	19,237	1.19
Water and sewer	6,402	0.40
Maintenance	65,656	4.05
Replacement equipment	--	--
Residue removal	†	†
Chemicals	3,400	0.21
Interest	39,179	2.42
Depreciation	78,070	4.82
Other overhead	3,209	0.20
Total operating and maintenance costs	$365,263	$22.55

* Based on costs incurred during September 1978.

† Cost included in salaries and employee benefit categories.

TABLE 11. NORTH LITTLE ROCK PROJECTED ANNUAL REVENUES*

Sources	Revenue
Steam production	$152,999
Commercial dumping fees	24,336
Total	$177,335
Per Mg of refuse processed (per ton)	$10.94 (9.92)

* Based on 1978 dollars.

With $365,263 as the projected annual operating and maintenance cost and $177,335 as the estimated annual revenue, the net annual operating cost will be $187,928. Table 12 presents the costs, revenues, and net costs per unit of refuse processed.

In summary, with the facility requiring an initial capital investment of $1,529,404 in 1977, its anticipated annual operation in 1978 dollars will cost $187,928 or $11.67 per Mg ($10.53 per ton) of refuse processed.

TABLE 12. NORTH LITTLE ROCK PROJECTED ANNUAL NET OPERATING COSTS*

	Cost	
	($/Mg)	($/ton)
Operating and maintenance costs	22.55	20.45
Revenue	10.94	9.92
Net cost of operation (tipping fee)	11.67	10.53

* Based on costs incurred during September 1978.

MARYSVILLE FACILITY

Description

This facility is located at the Truck Axle Division of the Rockwell International Corporation in Marysville, Ohio (see Figure 21). The system was intended for the twofold purpose of burning the division's solid waste, mostly packing and shipping scraps, and of providing energy for both heating and cooling the main building by recovering the combustion gas heat in the form of hot water.

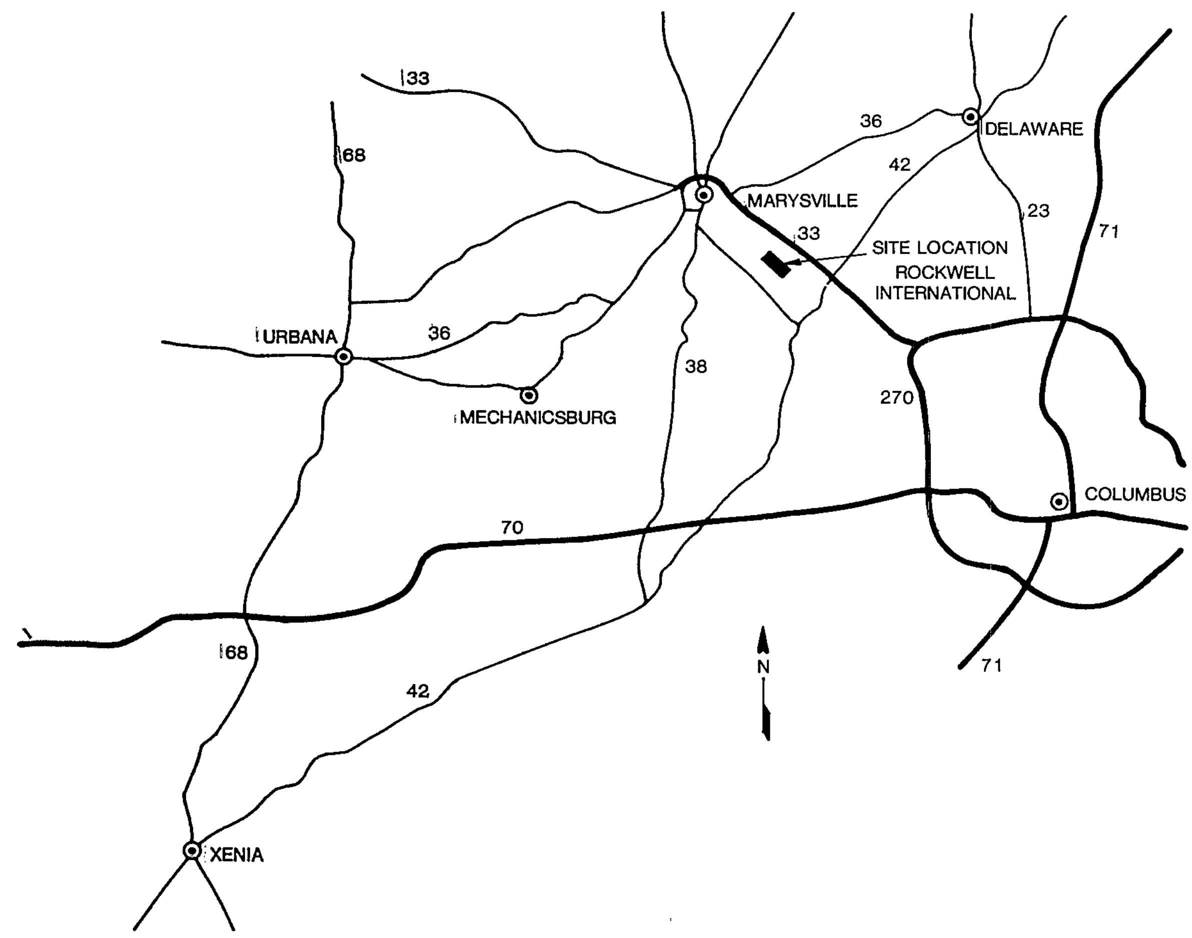


Figure 21. Vicinity map of Marysville (Rockwell International) vacility.

The waste-to-heat system includes a Kelley Model 1280 incinerator with a Kelley Model 72 feeder and a York-Shipley Series 565 firetube boiler. Figures 22 and 23 show a functional schematic of the entire system and a three-dimensional, cutaway drawing of the incinerator module, respectively. Both the primary and secondary chambers of the incinerator are outside the facility housing so that the main building is remote from excessive heat radiating from the incinerator (see Figure 24).

While the refuse is burned 16 hours a day 5 days per week throughout the year, the hot water is generated only as needed to maintain the prescribed temperatures.

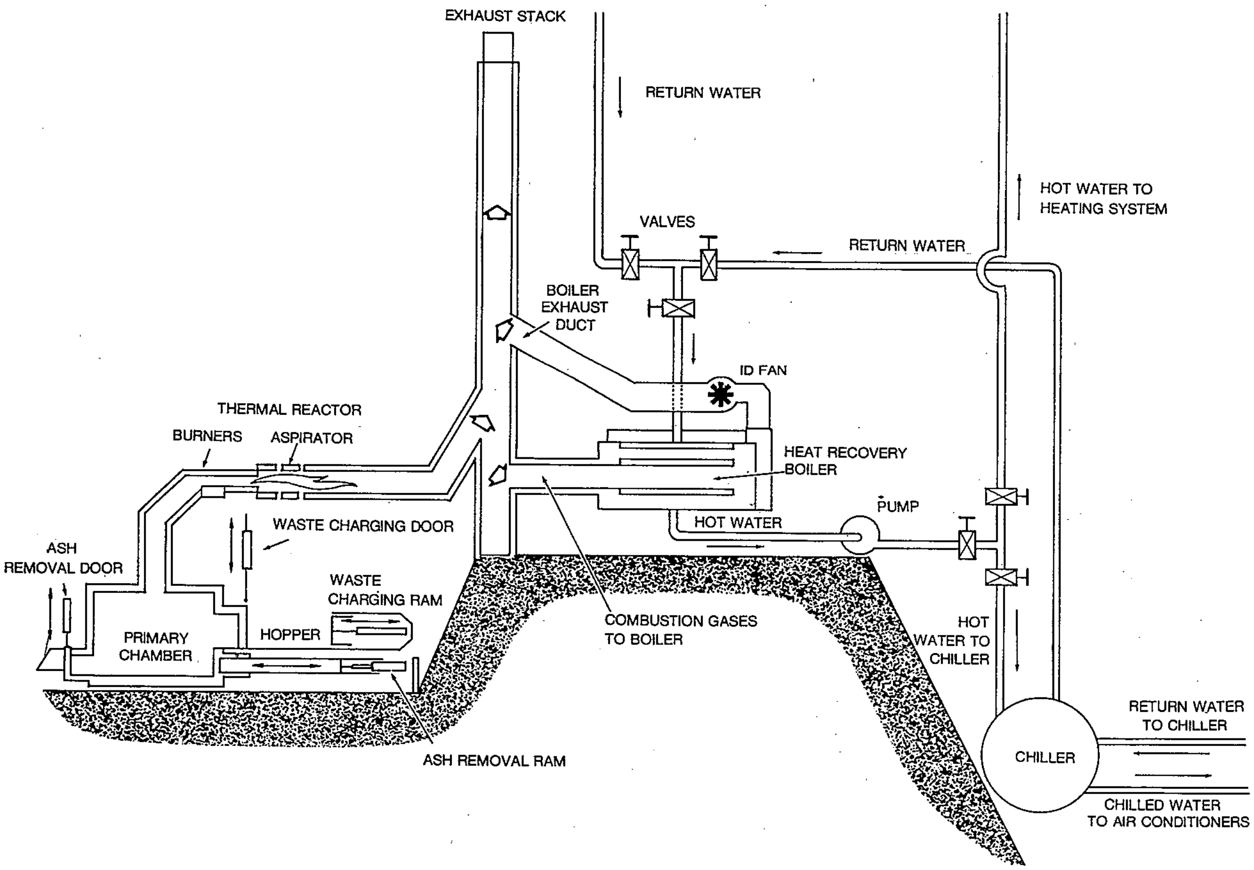


Figure 22. Functional schematic of incineration-heat recovery processes in Marysville facility.

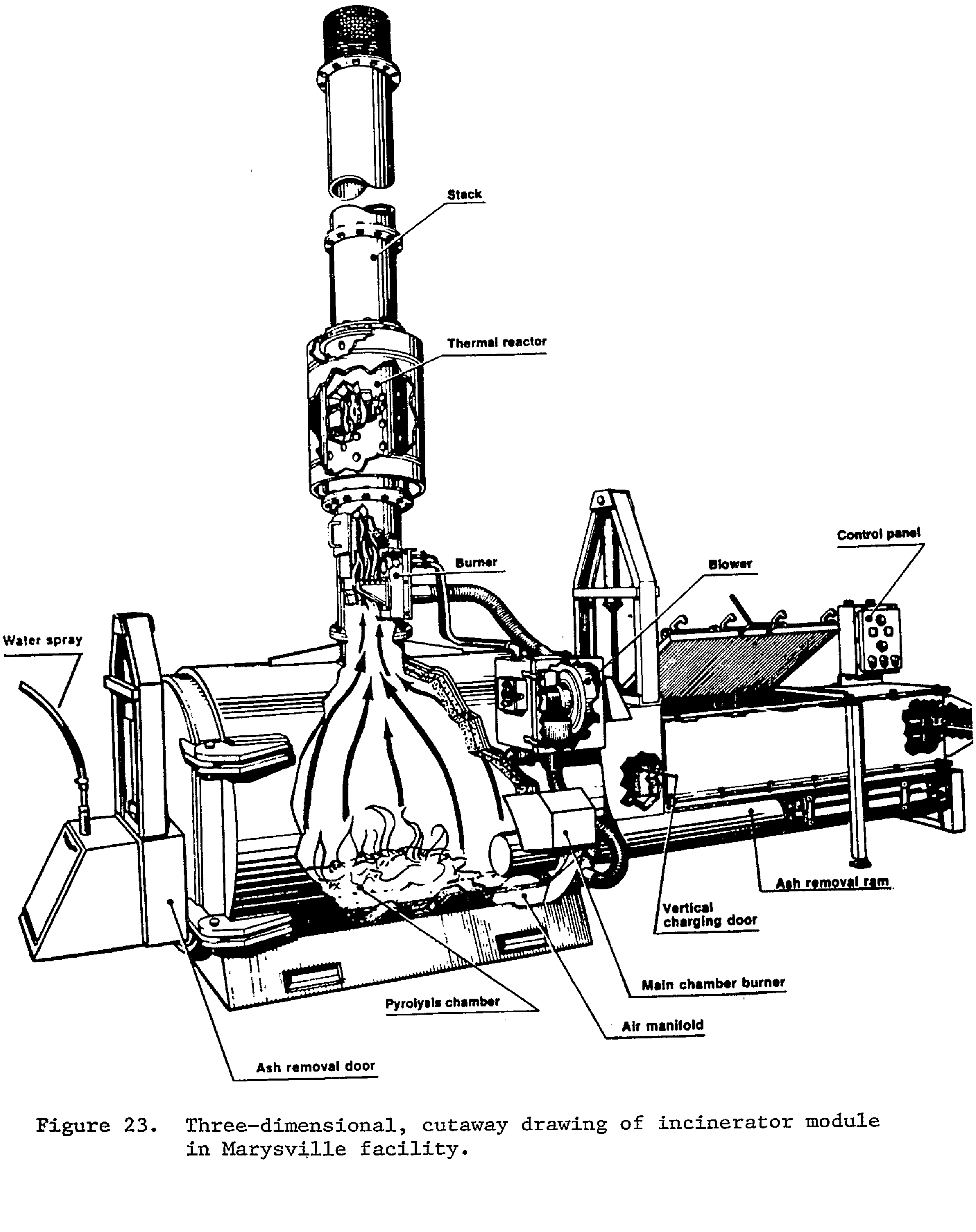


Figure 23. Three-dimensional, cutaway drawing of incinerator module in Marysville facility.

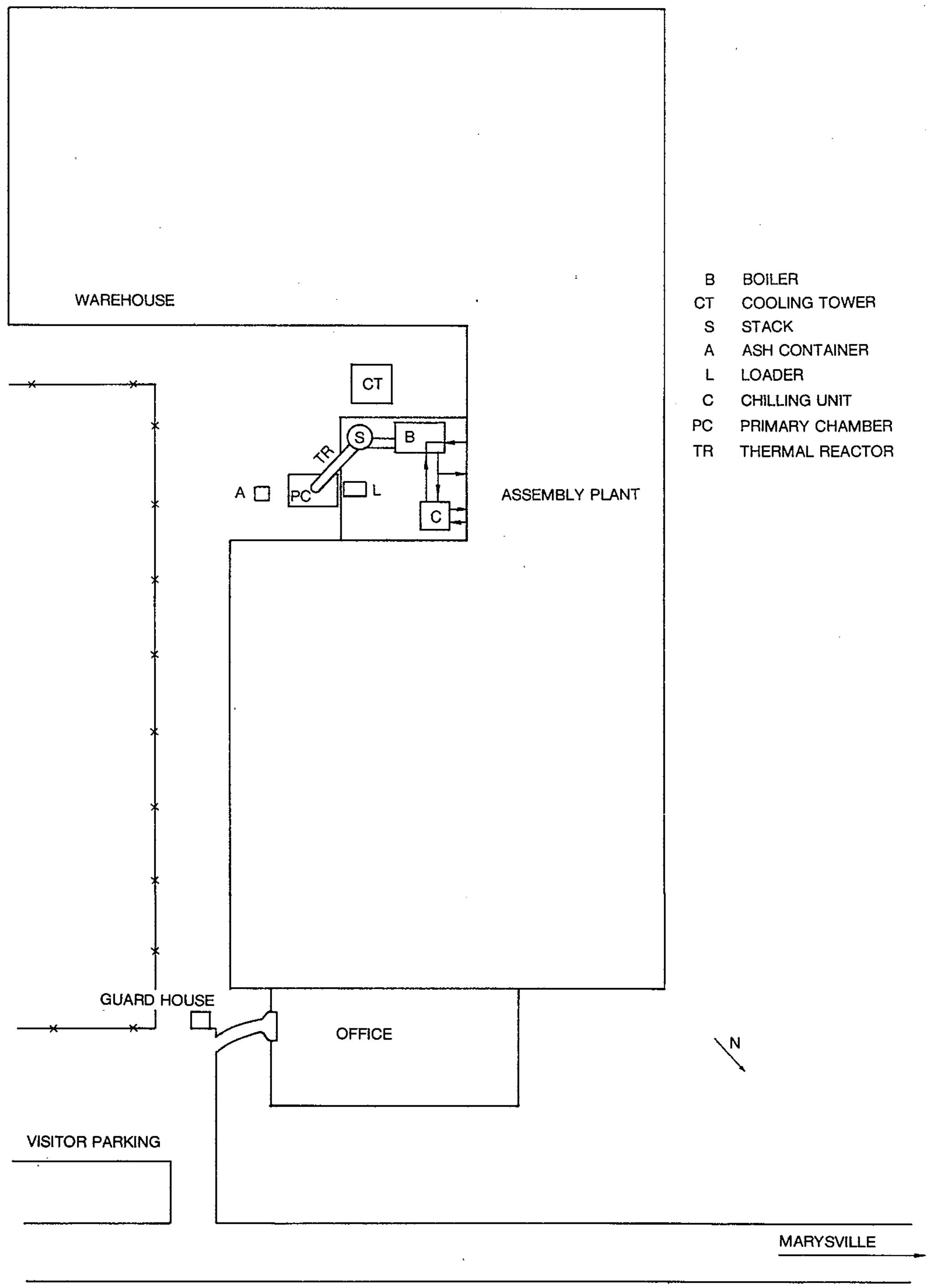


Figure 24. Plant layout of Marysville facility.

The incinerator system includes a loading hopper and ram module, a pyrolytic primary chamber with an automatic residue removal system, a secondary chamber, a hot water boiler system, and an exhaust gas stack. The process flow diagram is shown in Figure 25.

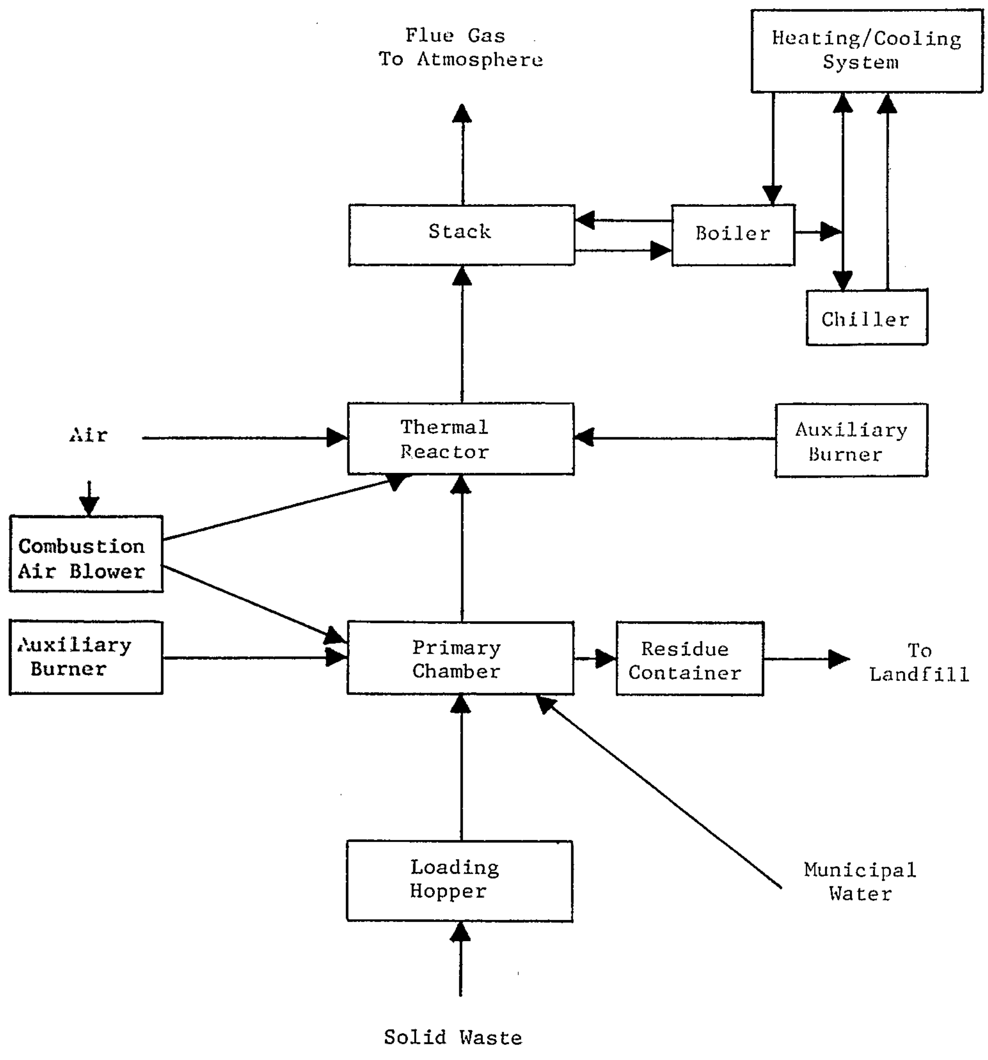


Figure 25. Flow diagram of incineration-heat recovery processes in Marysville facility.

Operation

Refuse Loading--

A fork lift vehicle transports the packing and shipping scraps and other solid waste in small containers to the refuse hopper. When the hopper door is opened, the vehicle operator lifts the containers and dumps the refuse into the hopper. Then the operator depresses the START button on the control panel to activate an automatic loading sequence.

Chamber Operations--

Manufacturer performance specifications indicate that the primary, or pyrolysis, chamber operates at 30 percent of the air required for stoichiometric combustion. The secondary chamber, or thermal reactor, operates at a maximum of 150 percent of stoichiometric air.

Introduction to Test Program

The facility was tested for 1-week periods during the months of April, July, and August 1978. The system was tested during the heat recovery period of the daily operation. Since the unit was used for heating and cooling of the plant, there was frequent cycling from energy to non-energy recovery during mild weather periods. Of these three tests, the July test had the most continuous and stable operating conditions. The data for this test, therefore, were used in the technical evaluation of the facility. The July test lasted for 120 hours. Energy was recovered during 75.5 hours of the 80 hours of operation, and the five daily burndown cycles totaled 40 hours. During the July test the incinerator operated at 63 percent of capacity. A total of 25,652 kg (56,552 lb) of wood and paper waste was burned at an hourly average of 340 kg (750 lb).

Technical Evaluation

During the three field tests, the refuse had a moisture content that ranged from 7 to 11 percent with an average of 9.3 percent. Of the 51,722 kg (114,027 lb) of refuse burned, as shown in Table 13, 65.7 percent was wood; 33.8 percent was paper; and the remaining 0.5 percent was plastics, paint, inerts, textiles, and rubber. On the average, the measured energy values of the wood and paper were 18.04 and 17.89 MJ/kg (7758 and 7693 Btu/lb), respectively. The residue had an average bulk density of 428 kg/m^3 (726 lb/yd^3) with 97 percent being inerts and the remaining 3 percent being combustibles. The refuse reduction through combustion was 95 percent by weight.

The weekly system mass balance for the July field test compares the mass flow entering and leaving the incinerator-heat recovery system. The system inputs were the refuse, the combustion fan air, the auxiliary gas, the quench water, and the afterburner air. The system outputs were the residue, hot water, and the boiler exhaust flue gas. The mass balance shown in Figure 26 covers two time periods: one for 75.35 hours while the system was in full heat recovery operation and the other for 44.62 hours while the system was in burndown cycles. Excluding the combustion air, the measured inputs totaled 42.6 Mg (47 tons). The air input could not be measured and had to be computed by the difference method.

TABLE 13. MARYSVILLE WEEKLY REFUSE COMPOSITION FOR APRIL, JULY, AND AUGUST TESTS

Category	April kg	April (lb)	July kg	July (lb)	August kg	August (lb)	Total kg	Total (lb)	Percent of Total
Total	13,151	(28,994)	25,652	(56,552)	12,919	(28,481)	51,722	(114,027)	
Wood	7,324	(16,147	18,684	(41,191)	7,985	(17,605)	33,993	(74,943)	65.7
Paper	5,768	(12,717)	6,940	(15,300)	4,782	(10,543)	17,490	(38,557)	33.8
Plastics			17	(38)	14	(31)	31	(69)	<.1
Paint	59	(130)					59	(130)	
Grease			12	(26)	20	(45)	32	(71)	<.1
Inert					82	(181)	83	(181)	.1
Textiles					13	(28)	13	(28)	<.1
Rubber					22	(48)	22	(48)	<.1

In the computation of the system mass balance on a per ton input basis, shown in Figure 26, the amounts of the combustion air and the afterburner section air had to be computed by subtracting the mass of the other inputs from the total mass output. This was done because the air masses could not be directly measured.

During the second field test, the energy recovered was 150 GJ (142 MBtu) as measured by the BTU meter and 180 GJ (174 MBtu) as computed by the heat loss method. The effectiveness and the thermal efficiency of the boiler were 90 and 82 percent, respectively.

Mass balance 120-hour test*

Source	Input: Mg per Mg refuse or Ton per ton refuse	Input: % of Total	Output: Mg per Mg refuse or Ton per ton refuse	Output: % of Total
Refuse	1.00	4.99		
Cooling spray water	0.65	3.24		
Natural gas	0.02	0.10		
Combustion air	18.39	91.67		
Flue gases			20.01	99.80
Residue, dry			.04	0.20
Total	20.06	100.00	20.05	100.00

* Total refuse input 25.6 Mg (28.3 tons).

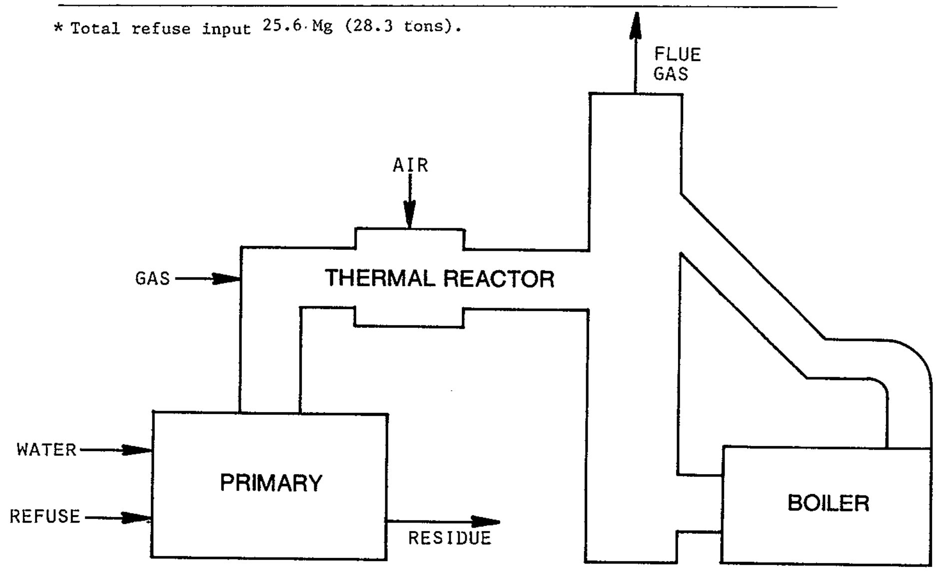


Figure 26. Mass balance for incineration-heat recovery processes in Marysville faciltiy during the 120-hour (75.5-hour heat recovery) July field test.

The energy balance in Figure 27 compares the measured energy inputs and outputs on a per ton input basis. For this balance, the inputs were refuse, quench water, auxiliary fuel, and electricity. The outputs were the hot water generated, sensible heat and remaining energy in the residue, heat lost by radiation and convection, and sensible heat in the flue gases. The energy inputs and outputs for the 120-hour test totaled 436 GJ and 409 GJ (413 and 388 MBtu), respectively. The difference of 27 GJ (25 MBtu) or 6 percent of the energy input was not accounted for.

As shown in Figure 27 for the energy balance, 19 percent of the heat was lost by radiation and convection, and 14 percent was lost during the burndown cycles.

Energy balance 120-hour test*

Source	Input: GJ per Mg of refuse	Input: (MBtu per Ton of refuse)	Input: % of total	Output: GJ per Mg of refuse	Output: (MBtu per Ton of refuse)	Output: % of total
Refuse	16.36	(14.07)	96.4			
Electricity	0.12	(0.10)	0.7			
Natural gas						
Heat recovery	0.29	(0.25)	1.7			
Burndown	0.21	(0.18)	1.2			
Residue				0.03	(.03)	0.2
Radiation and Convection						
Heat recovery				2.26	(1.94)	14.4
Burndown				0.82	(0.71)	5.3
Flue gases						
Heat recovery				4.19	(3.60)	26.7
Burndown				2.27	(1.95)	14.5
†Hot water (measured)				6.09	(5.24)	38.9
	16.98	(14.60)	100.0	15.66	(13.47)	100.0

*Total refuse input 25.6 Mg (28.3 ton)
†Hot water output by difference 7.41 GJ/Mg refuse (6.37 MBtu/ton)

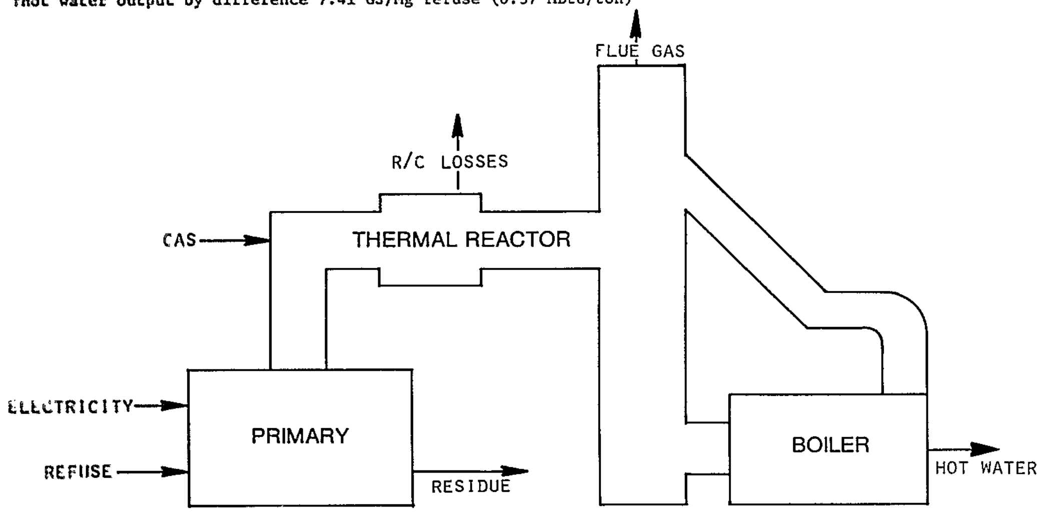


Figure 27. Energy balance for incineration-heat recovery processes in Marysville facility during the 120-hour (75.5-hour heat recovery) July field test.

The system energy efficiency during the heat recovery periods as calculated by the heat loss method was 54 percent. The system energy efficiency for a week-long test, including heat recovery and burndown periods was 42 percent. The net efficiencies were 54 and 43 percent, respectively.

While the facility was capable of handling all incoming refuse and of meeting the plant's heating and cooling demands, it operated at only 63 percent of capacity during the two 8-hour shifts.

The delivery of waste varied widely in amounts and times. The unit was underfed most of the time, but occasionally it was overfed. This is evidenced by Figure 28 which shows an overload period when the boiler entrance temperature was higher than the secondary chamber temperature. Figure 29 shows gas emission peaks caused by overfeeding during the same period.

One man could readily operate the facility. Corrective maintenance required (1) once or twice a week removal of residue, (2) the weekly removal of particulate accumulations from the blades on the induced draft fan that made the fan vibrate excessively toward the end of the week, and (3) the semiannual removal of slag accumulations from the boiler tubes.

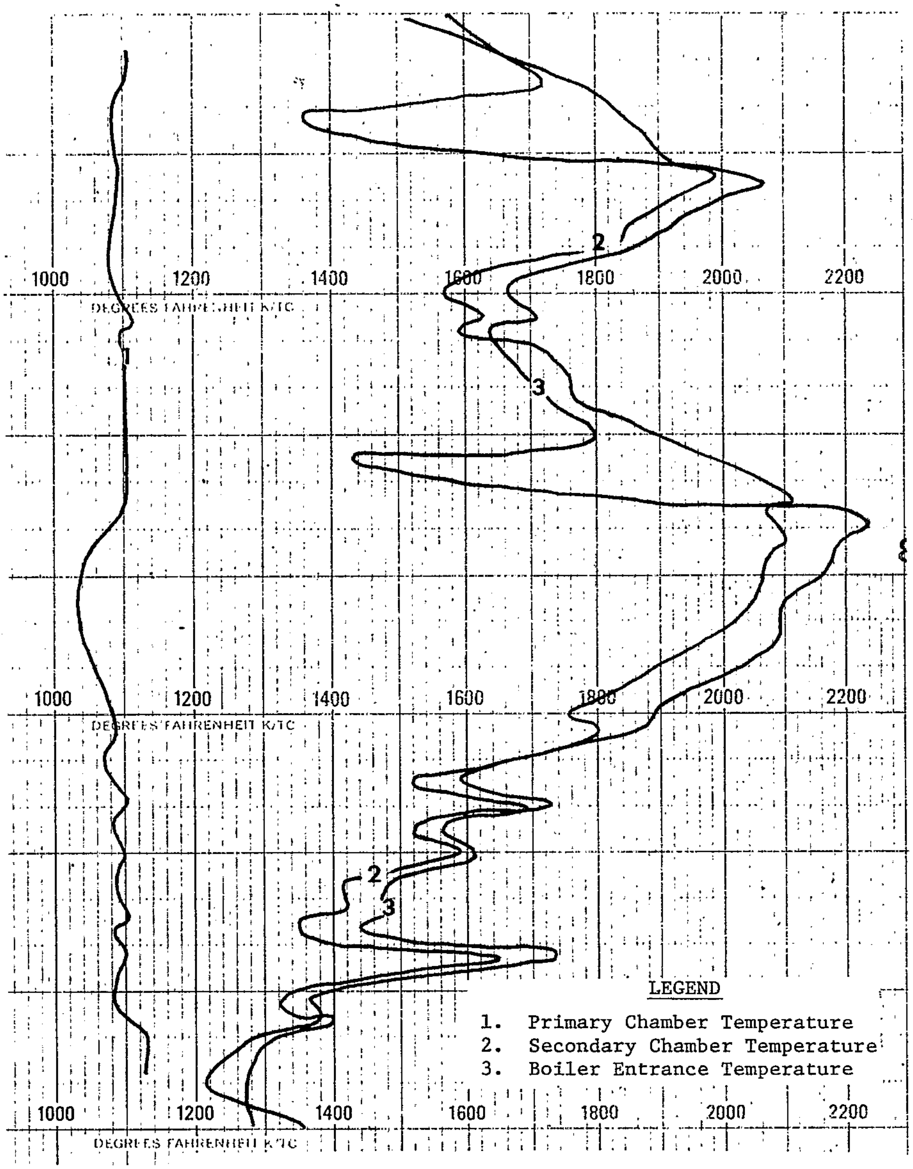


Figure 28. System temperatures during peak loading periods in Marysville facility.

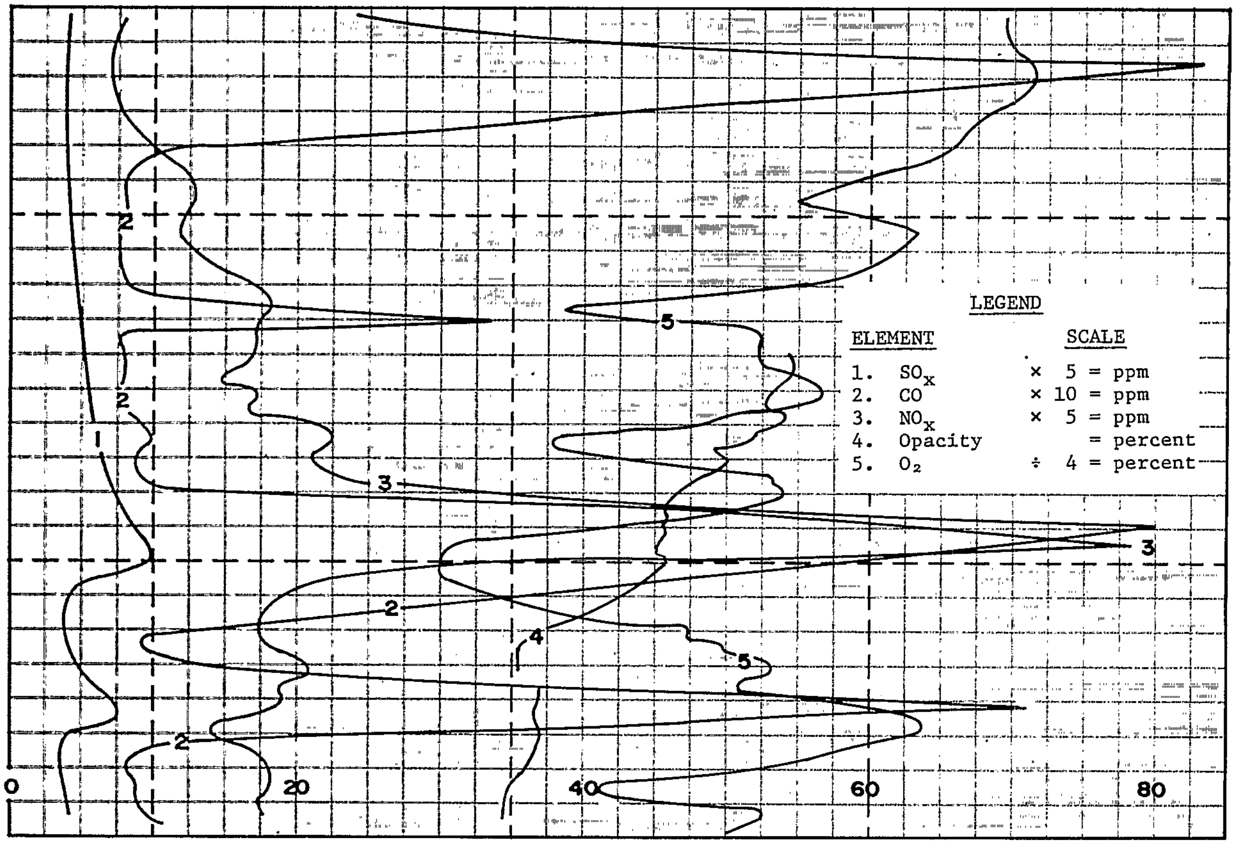


Figure 29. Stack emissions during peak loading periods in Marysville facility.

Environmental Evaluation

For the July test, Table 14 presents the flue gas emissions in terms of grains or ppm and of pounds per hour per ton of refuse processed. Table 15 summarizes the emissions for each of the three test periods. The size distribution analysis of the particulates during the July test revealed that 85 percent by weight of the particulates were smaller than 7 μm. The concentrations of chloride ranged from 4 to 136 mg/m^3 (3 to 94 ppm) and averaged 38 mg/m^3 (26 ppm) while those of fluoride ranged from 0.2 to 2.0 mg/m^3 (0.3 to 2.6 ppm) and averaged 0.9 mg/m^3 (1.1 ppm) over the three test periods. The light (C_1 to C_6) hydrocarbons varied widely in the range from 1.8 to 1423 mg/m^3 (1.2 to 936 ppm).

No significant amounts of pollutants were found in the residue or its laboratory-produced leachate (see Table 16). Within the facility building, the fugitive dust levels were low, and no noise levels exceeded the OSHA limits (see Figure 30). No significant amounts of pollutants were found at the upwind or downwind ambient air sample sites which were both at a 91.4-m (300-ft) distance from the boiler exhaust stack.

TABLE 14. MARYSVILLE POLLUTANT EMISSION RATES FOR JULY TEST

Pollutant	Emission rate			
	Maximum	Average	Minimum	lb/ton refuse charged
Particulate	0.111 gr/SCF*	.049 gr/SCF*	.033 gr/SCF*	2.01
SO_x	31 ppm	8 ppm	<5 ppm	.44
NO_x	125 ppm	30 ppm	6 ppm	1.19
CO	<1000 ppm	240 ppm	17 ppm	5.81
HC	2285 ppm	765 ppm	21 ppm	10.4
Lead		624 $\mu g/m^3$		0.02

* Corrected to 12 percent CO_2.

TABLE 15. MARYSVILLE SUMMARY OF STACK EMISSIONS FOR APRIL, JULY, AND AUGUST TESTS

	Field test											
	Test 1: April 24-28, 1978				Test 2: July 7-17, 1978				Test 3: August 21-25, 1978			
Emissions (units)	Max	Avg	Min	Std Dev	Max	Avg	Min	Std Dev	Max	Avg	Min	Std Dev
Particulate (gr/SCF)*		Not Isokinetic			0.111	0.049	0.033	0.024	0.133	0.088	0.060	0.027
Particulate (g/m^3)*					0.253	0.111	0.075	0.054	0.303	0.201	0.137	0.061
Chlorides (mg/m^3)	23.0	13.9	5.8	7.1	136	78.6	9.3	49.7	31.7	11.4	4.2	8.6
Fluorides (mg/m^3)	0.7	0.5	0.2	0.2	2.0	0.9	0.3	0.6	1.7	1.0	0.7	0.3
O_2 (percent)	17.8	14.0	10.7	1.7	18.5	14.3	5.4	2.8	19.4†	15.9	12.4	1.9
CO_2 (percent)		No Data			10.5	9.7	7.2	1.01	9.0	5.6	3.4	1.8
CO (mg/m^3)	>1000	148	26	27	>1000	279	20	129	363	108	8	93
NO_x (mg/m^3)	191	64	<10	38	239	59	11	47	143	33	<10	34
SO_x (mg/m^3)	37	16	<13	7.0	82	15	<13	21	56	9.0	<13	10
Particulate size (μm)#		No Data			29	0.3	<0.3	--	27	0.7	<0.7	--
Hydrocarbons (mg/m^3)ϕ	105	17.9	1.8	--	1400	475	13.7	--	204	70	9.1	--
Opacity (percent)		No Data		--		No Data		--	42	--	15	--
H_2O (percent by volume)	14.4	8.4	1.8	--	16.4	14.5	13.3	--	14.4	9.6	1.8	--
Flue gas temperature (°F)	150	195	227	--	237	280	291	--	217	326	459	--
Flue gas flow (SCFM)	1790	2195	3155	--	6830	2870	2210	--	2490	2250	1700	--
Flue gas flow (ACFM)	3765	2773	2205	--	9350	4075	3100	--	3920	3445	2235	--

* Corrected to 12 percent CO_2
† During charging hours only
\# Average is mass mean diameter
ϕ Average CH_4-C_4H_{10}

TABLE 16. MARYSVILLE RESIDUE LEACHATE PARAMETER AND COMPONENT VALUES

		Water Blank	Test 1	Phosphate Buffer Test 2
pH		5.52	10.24	6.2
Conductivity	umhos	2.78	379.00	3700
Alkalinity	mg/ℓ	1.10	78.10	232
TKN	mg/ℓ	6.95	2.59	7.05
Hardness	mg/ℓ	2.00	112.30	<0.1
TOC	mg/ℓ	3.10	5.00	<1
Ortho-Phosphate	mg/ℓ	0.005	0.002	1230
Total Phosphate	mg/ℓ	0.01	0.063	1360
Sulfide	mg/ℓ	<0.002	<0.002	<.003
Chloride	mg/ℓ	ND	1.51	43
Acidity	mg/ℓ	5	ND	1938
Total Dissolved Solids	mg/ℓ	<1	236	6012
Ammonia as N	mg/ℓ	0.216	0.170	0.076
COD	mg/ℓ	ND	ND	52.5
Sulfate	mg/ℓ	<1.00	68.00	0.19
Bromide	mg/ℓ	<0.100	<0.100	0.64
Fluoride	mg/ℓ	0.058	0.662	0.363
Boron	mg/ℓ	<0.1	2.6	65.6
Mercury	μg/ℓ	<0.1	<0.1	–
Cadmium	μg/ℓ	<1	<1	–
Antimony	μg/ℓ	<1.0	18.7	–
Lead	μg/ℓ	<1	1.3	–
Chromium	μg/ℓ	<1	3280	–
Arsenic		ND	ND	–
MBAS	mg/ℓ	–	–	.121
Phenols	mg/ℓ	–	–	.080
Cyanide	mg/ℓ	–	–	.002

ND = None detected

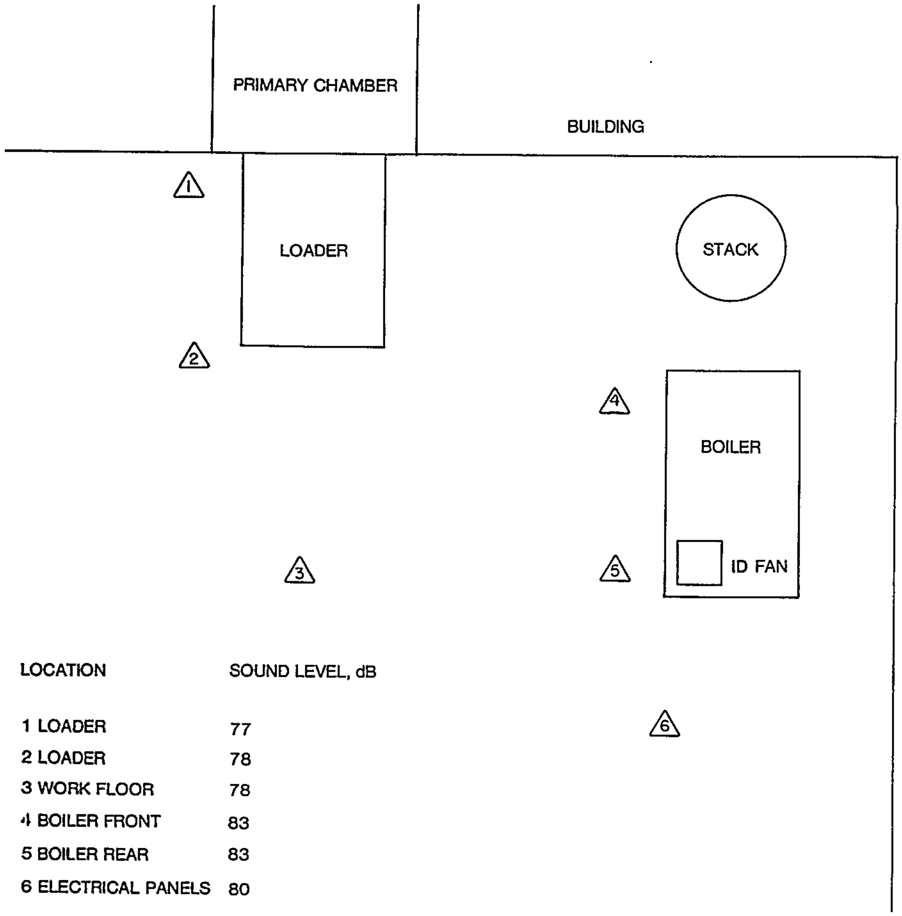


Figure 30. In-plant noise-level plot for Marysville facility.

Of the pollutants detected in the EPA Level 1 analysis, antimony, arsenic, mercury, and heavy organic compounds were found consistently in small amounts. Other metals such as lead, cadmium, chromium, and barium were found occasionally in small amounts (see Table 17). The contaminants were found in the stack emissions and the residue.

Economic Evaluation

The total cost of the facility was $509,949 in 1977. Table 18 presents the total cost breakdown by EPA cost categories, and Table 19 presents the unit operational costs which were obtained from records maintained by the plant engineer. Table 20 presents a comprehensive economic evaluation for each cost center based on actual operating conditions during July.

TABLE 17. MARYSVILLE SUMMARY OF ELEMENTS DETECTED IN STACK EMISSION FILTERS

Element	Emission rate	
	Concentration in gas ($\mu g/m^3$)*	Emission factor g/Mg of refuse†
Silicon	2.95	.042
Iron	520.	7.45
Aluminum	2,202.	31.5
Sodium	13,839.	198.0
Calcium	1,749.	25.0
Potassium	450.	6.44
Magnesium	640.	9.17
Lead	624.	8.93
Zinc	2,724.	39.0
Cadmium	428.	6.14
Beryllium	0.09	.0014
Titanium	0.419	.0060
Chromium	1.66	.0237
Copper	19.3	.277
Nickel	1.78	.0255
Manganese	11.4	.164
Lithium	2.10	.030
Antimony	1.69	.0243
Boron	98.1	1.41
Tin	3.33	.0477
Vanadium	2.30	.033

* Concentrations based on a composite of five filters from July test period.
† g/Mg ÷ 500 = lb/ton

TABLE 18. MARYSVILLE CAPITAL COSTS*

	Incineration	Heat Recovery
Land	$ 1,000	$ 2,000
Site preparation	†	†
Design		12,500
Construction	7,000	82,166
Real equipment	69,302	335,081
Total capital investment	77,302	432,647

* Based on 1977 dollars.

† Site preparation costs were not identified in Rockwell International Corporation accounting records.

TABLE 19. MARYSVILLE UNIT COST DATA*

Salary rates (annual, FY 78):	
General helper	$14,500
Employee benefits rate	$5,800
Natural gas	$0.091/kℓ
Electricity rate	$0.0282/kwh
Water rate	$0.24/1000ℓ
Sewer	†
Chemical (NC-1) costs	$2.30/ℓ

*Based on costs incurred in 1978.
†On-site disposal (septic system).

Although the incinerator-heat recovery facility was installed to provide an assured energy supply for the plant's heating and air conditioning systems, and not to produce revenue by itself; it indirectly produces a revenue by eliminating the costs previously expended for the propane used during the winter, for the electricity used during the summer, and for the compactor and container used to dispose of the solid waste.

During the three test periods, the average heat recovery rate was 23,025 MJ (21.8 MBtu) per day. With estimated heating and cooling seasons of 128 and 122 days, respectively, and with the previous propane and electricity costs of $0.00404 and $0.00769 per MJ ($3.83 and $7.29 per MBtu), respectively, the facility yielded an annual savings, or annual revenue equivalent, of $23,557. The costs of the solid waste disposal method that were replaced amounted to $27,500 per year or $24.21 per Mg ($22.95 per ton). The net operating costs by system function are shown in Table 21.

TABLE 20. MARYSVILLE PROJECTED ANNUAL OPERATING AND MAINTENANCE COSTS PER COST CENTER*

Cost classification	Total cost	Cost Center: Receiving	Incineration	Heat recovery	General plant
Salaries	$ 14,500	$ 7,250	$ 5,800	$ 1,450	
Employee benefits	5,800	2,900	2,320	580	
Fuel	9,914		9,914		
Water and sewer	163		163		
Electricity	829	45	235	549	
Maintenance	15,004	828	3,498	5,818	$ 4,860
Chemicals	65			65	
Interest	24,480	687	2,918	16,592	4,283
Depreciation	34,815	1,255	5,300	24,499	3,671
Sub total	$105,570	$12,965	$30,148	$49,553	$12,904
General plant allocation:		3,045	4,084	5,775	
Total	$105,570	$16,010	$34,232	$55,328	

*Based on 1978 dollars.

TABLE 21. MARYSVILLE NET OPERATING COST BY SYSTEM FUNCTION*

	Incineration			Incineration and Heat recovery		
	($/yr)	($/Mg)	($/ton)	($/yr)	($/Mg)	($/ton)
Operating and maintenance	(34,232)		(28.53)	(105,570)		(87.98)
Disposal savings	27,500		22.95	27,500		22.95
Energy savings				23,557		19.63
Net savings (cost) of operation	(6,732)	(5.92)	(5.61)	(54,513)	(47.93)	(45.43)

* Based on 1978 dollars, 1200 tons annually.
Operating cost includes interest and depreciation.

In summary, the facility required an initial capital investment of $509,949 in 1977. Of this amount, $77,302 was spent on the incineration system to dispose of the solid waste and $432,647 was spent to recover and utilize the energy. The anticipated net annual operational cost of the facility in 1978 dollars would be $105,570 or $47.93 per Mg ($45.40 per ton). The as-operated economics would produce an after tax positive cash flow of $85,400 the first year and $7,600 for each year thereafter. The first year value includes all of the 10 percent investment tax credit and the additional 10 percent energy credit effective in 1978.

SECTION 4

OPERATING COST PROJECTIONS

EVALUATED FACILITIES

Since the two evaluated facilities at North Little Rock, Arkansas, and Marysville, Ohio, were not operating at optimum conditions when they were monitored, the cost and revenue for the as-operated conditions at each facility were extrapolated to the optimum conditions. If the North Little Rock facility had operated under optimum conditions, that is, with the feed rate and steam production equal to the design capacities of 3.6 Mg (4 tons) and 9090 kg (20,000 lb) per hour, respectively, it would have had a total revenue and a revenue per Mg (per ton) of refuse processed that would have been $127,773 and $3.08 per Mg ($2.79 per ton), respectively, more than the revenue for the as-operated conditions. The optimum operating costs are given in Table 22, and the revenues are shown in Table 23. If the Marysville facility had operated under optimum conditions, that is, with a daily feed rate and energy recovery equal to the design capacities of 545 kg (1200 lb) and 6.17 GJ (5.85 MBtu), respectively, it would have yielded a savings of $104,270 or $31.94 per Mg ($28.96 per ton) of refuse processed. The optimum operating costs are shown in Table 24, and the revenues are shown in Table 25. These revenues will give a payback within 5 years.

FACILITIES IN GENERAL

To estimate the operating costs at municipal and industrial facilities in general, the 1978 economic data for the various operating parameters at the two evaluated facilities were adapted in an empirical method to develop equations expressing the relationship between the net loss or profit and three independent parameters, namely refuse feed rate, shifts per week, and operating percentage of rated capacity.

To determine the net operating costs of the municipal facilities, the following assumptions were made: (1) the average employee salary is $20,800 per year including benefits, (2) the auxiliary fuel used is natural gas at a unit cost of $0.088/kℓ ($2.50 MCF), (3) the electric power unit cost is $0.035/kwh, (4) the unit cost of water is $0.24/kℓ ($0.90/1000 gal), (5) the ratio of the wet residue to the as-received refuse is 0.40, (6) the cost of residue disposal is $4/Mg, (7) the interest rate is 7 percent, (8) the estimated life of the facility is 15 years, (9) the heat content of the refuse is 10.4 MJ/kg (4500 Btu/lb), and (10) the recovered energy value is $0.00245/MJ ($2.60/MBtu).

TABLE 22. NORTH LITTLE ROCK PROJECTED OPTIMUM OPERATING AND MAINTENANCE COSTS*

Item	Cost ($/yr)	Cost ($/Mg)
Salaries	$111,284	$ 5.11
Employee benefits	15,750	0.72
Fuel - no. 2 diesel	4,608	0.21
Natural gas	16,704	0.77
Gasoline	3,888	0.18
Electricity	19,237	0.88
Water and sewer	8,121	0.37
Maintenance	65,656	3.02
Replacement equipment	--	--
Residue removal	†	†
Chemicals	5,033	0.23
Interest	39,179	1.80
Depreciation	78,070	3.59
Other overhead	3,209	0.15
Total operating and maintenance costs	$370,739	$17.03

* Based on 1978 dollars.

† Cost included in salaries and employee benefit categories.

TABLE 23. NORTH LITTLE ROCK PROJECTED OPTIMUM ANNUAL REVENUES*

Revenues	Cost
Steam production	$280,772
Tipping fees	24,336
Total	$305,108
Per Mg of refuse processed (per ton)	$14.02 (12.72)

* Based on 1978 dollars.

TABLE 24. MARYSVILLE PROJECTED OPTIMUM OPERATING AND MAINTENANCE COSTS*

Item	Cost ($/yr)	Cost ($/Mg)
Salaries	21,750	6.66
Employee benefits	5,438	1.66
Fuel	14,871	4.55
Electricity	1,244	0.38
Water and sewer	244	0.07
Maintenance	15,004	4.59
Chemicals	98	0.03
Interest	24,480	7.49
Depreciation	34,815	10.66
Total	117,944	36.12

* Based on 1978 dollars.

TABLE 25. MARYSVILLE PROJECTED OPTIMUM NET OPERATION COSTS*

Item	Cost ($/yr)	Cost ($/Mg)	Cost ($/ton)
Operating and maintenance	117,944	36.12	32.76
Disposal savings	82,620	42.75	38.77
Energy savings	139,594	25.30	22.95
Net savings	104,270	31.94	28.96

* Based on 1978 dollars.

To determine the net operating cost of the industrial facilities, the following assumptions were made: (1) the average employee salary is $20,800 per year including benefits, (2) the auxiliary fuel used is natural gas at a unit cost of $0.088/kℓ ($2.50 kCF), (3) the electric power unit cost is $0.035/kwh, (4) the unit cost of water is $0.24/kℓ ($0.91/1000 gal), (5) the ratio of the wet residue to the as-received refuse is 0.10, (6) the cost of residue disposal is $4/Mg, (7) the interest rate is 12 percent, (8) the depreciation period is 7 years, (9) the heat content of the refuse is 7.91 MJ/kg (7500 Btu/lb), and (10) the recovered energy value is $0.00311/MJ ($3.28/MBtu). The higher energy value can be used because the industry is the energy user and does not have to sell energy at a derated price.

The resultant data for the municipal and industrial facilities are summarized in Figures 31 and 32, respectively, where the curves A through F represent possible operational modes. In the development of these figures, it was assumed that the refuse would be generated only 5 days per week. The 7-day operational mode is burning a 5-day per week refuse generation over a 7-day per week refuse processing. At 100 percent of rated capacity, the net operating costs for 15 and 21 shifts per week in municipal systems are nearly the same. As seen in Figure 31, the net operating cost per unit of refuse feed rate is $10/Mg ($9/ton) or less for the capacity range between 45 and 90 Mg/5 days (50 and 100 tons/5 days).

With refuse feed rates in the range of 27.5 Mg/5 days (25 tons/5 days) and above, industrial facilities will yield a positive balance, or revenue, in the net operating cost computation when they operate at 100 percent of rated capacity but an actual cost in the net operating cost computation when they operate at 50 percent of rated capacity. This cost must be compared with the cost of alternative waste disposal methods and fuel sources to determine the economic feasibility of a proposed system.

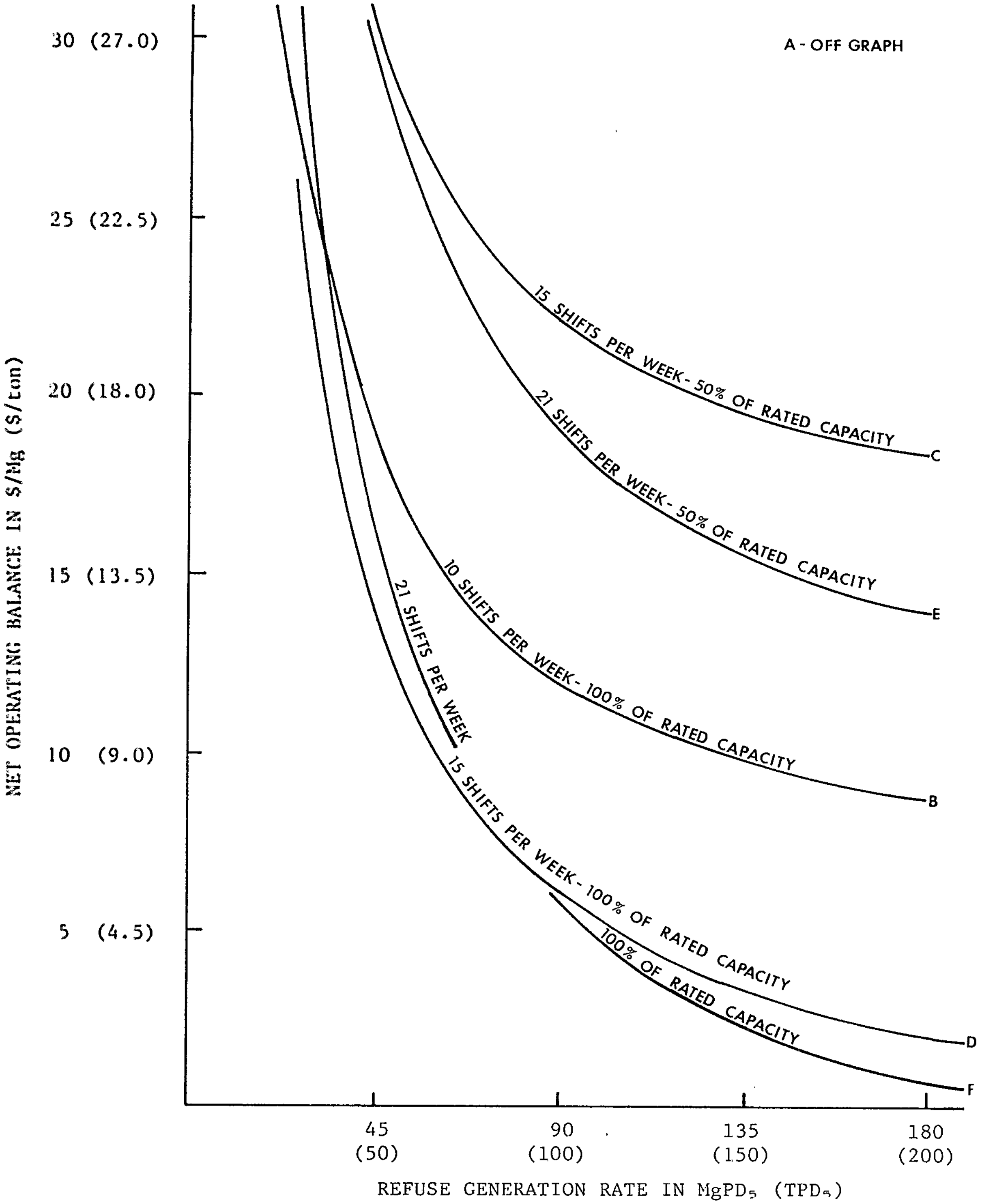


Figure 31. Estimated operating cost as a function of refuse feed rate, shifts per week, and operating percentage of rated capacity for municipal small modular incinerators.

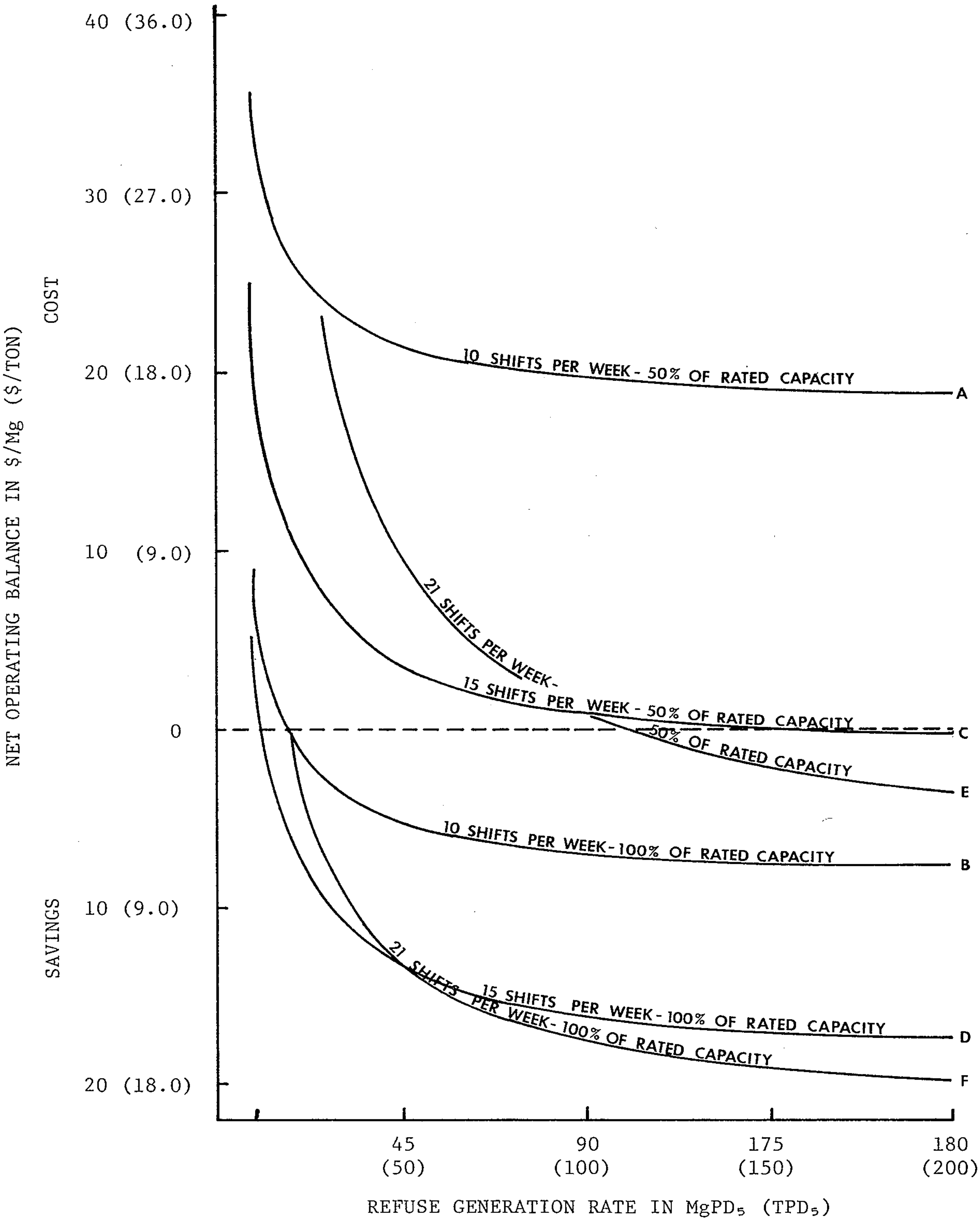
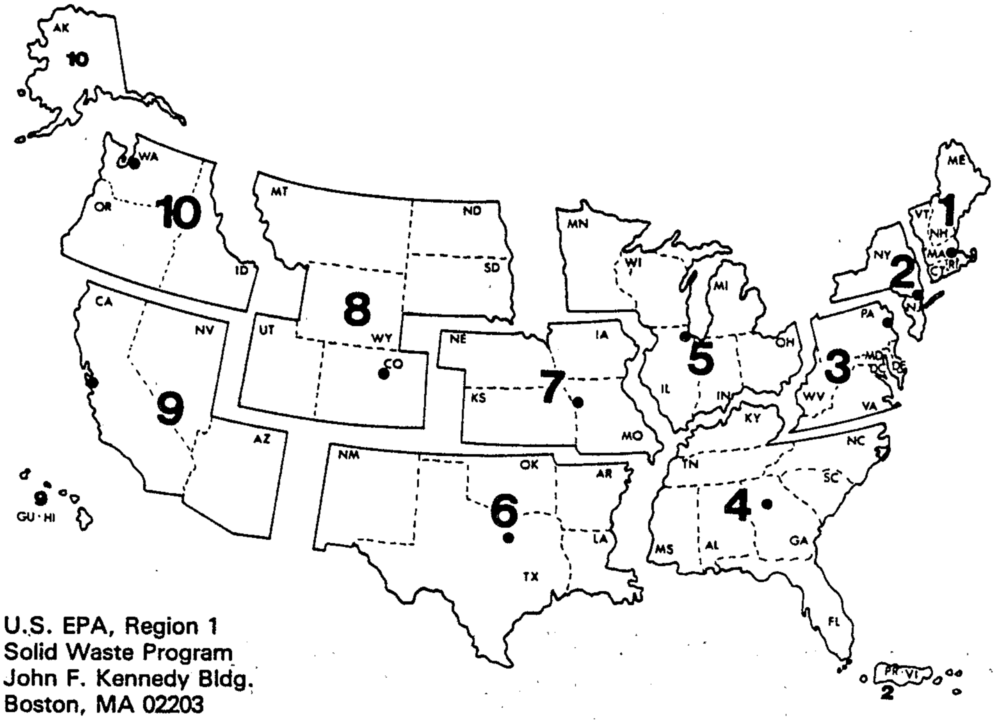


Figure 32. Estimated operating cost as a function of refuse feed rate, shifts per week, and operating percentage of rated capacity for industrial small modular incinerators.

EPA REGIONS



U.S. EPA, Region 1
Solid Waste Program
John F. Kennedy Bldg.
Boston, MA 02203
617-223-5775

U.S. EPA, Region 2
Solid Waste Section
26 Federal Plaza
New York, NY 10007
212-264-0503

U.S. EPA, Region 3
Solid Waste Program
6th and Walnut Sts.
Philadelphia, PA 19106
215-597-9377

U.S. EPA, Region 4
Solid Waste Program
345 Courtland St., N.E.
Altanta, GA 30308
404-881-3016

U.S. EPA, Region 5
Solid Waste Program
230 South Dearborn St.
Chicago, IL 60604
312-353-2197

U.S. EPA, Region 6
Solid Waste Section
1201 Elm St.
Dallas, TX 75270
214-767-2734

U.S. EPA, Region 7
Solid Waste Section
1735 Baltimore Ave.
Kansas City, MO 64108
816-374-3307

U.S. EPA, Region 8
Solid Waste Section
1860 Lincoln St.
Denver, CO 80295
303-837-2221

U.S. EPA, Region 9
Solid Waste Program
215 Fremont St.
San Francisco, CA 94105
415-556-4606

U.S. EPA, Region 10
Solid Waste Program
1200 6th Ave.
Seattle, WA 98101
206-442-1260

μσ1833
SW-797