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Water-Related Environmental Control Requirements at Municipal Solid Waste-to-Energy Conversion Facilities

September 1980

Prepared for:
U.S. Department of Energy
Assistant Secretary for Environment
Office of Environmental Compliance and Overview
Environmental and Safety Engineering Division

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September 1980

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PART I: EXECUTIVE SUMMARY

1.1. INTRODUCTION

The use of large-scale mechanical systems for processing and burning municipal solid wastes for energy production has been receiving a great deal of consideration since the passage of the Solid Waste Disposal Act of 1965 [1] as amended by the Resources Recovery Act of 1970 (P.L. 91-512) [2] and the Resources Conservation and Recovery Act of 1976 (P.L. 94-580) [3]. Ideally, these systems should solve two problems--production of steam or electrical energy, thereby saving valuable fuel resources, and disposal of solid wastes with a reduced reliance on unpopular and perhaps environmentally unsound dumps and landfills. Studies to date have been directed primarily at evaluating the mechanical aspects of the individual system elements used for processing the solid waste and for energy production. Water-related environmental impacts and water pollution control technology requirements for such systems have been given little consideration. Almost no attention has been directed toward possible problems of excessive use of water or production and treatment of wastewater which might present mechanical, environmental or economical limitations to design and application.

Consequently, the study described in this report was initiated to evaluate water use and wastewater production at municipal solid waste-to-energy conversion systems, to identify water pollution control technology requirements, and to identify water-related limitations to

their design and commercialization. This study program consisted of three phases. Phase I involved surveying existing waste-to-energy conservation technology through literature reviews and site visits and by working with design engineers and manufacturing firms. This survey documented available information on points of water use and wastewater production and served as a basis for design of a more detailed program to assess the water use management and water-related environmental control technology requirements of existing and proposed municipal solid waste-to-energy conversion systems [4].

Phases II and III were designed to evaluate the ability or inability of conventional and advanced wastewater treatment processes to remove specific organic and inorganic compounds from wastewaters produced at municipal solid waste-to-energy conversion facilities.

The ultimate goals of the project were

1. To identify points of excessive water use and to make recommendations for improvements in water use management,
2. To identify points of wastewater production and associated problems with treatability, corrosion, abrasion, or plant operation,
3. To identify design and operating changes that can reduce water use and wastewater production,
4. To identify the level of wastewater treatment technology needed to eliminate adverse water-related environmental impacts or to treat wastewaters sufficiently so that they can be discharged to water courses or to municipal wastewater treatment plants,

5. To identify wastewater treatment and residue disposal requirements that might limit commercial feasibility of any of the solid waste-to-energy conversion processes investigated, and
6. To estimate the costs associated with water-related environmental controls.

1.2. DESCRIPTION OF EVALUATION PROGRAM

Solid waste processing operations designed for resource recovery and energy production throughout the United States can be grouped under four major categories:

1. Mass burning, with direct production of steam for use as a supplemental energy source;
2. Mechanical processing to produce a refuse-derived fuel (RDF) for co-firing in gas, coal or oil-fired power plants;
3. Pyrolysis for production of a burnable oil or gas;
4. Biological conversion of organic wastes to methane.

The mass-burning category includes waterwall and refractory incinerators. Refuse-derived fuel and materials recovery systems can be subdivided into two categories: dry mechanical processing and wet pulping. Pyrolysis units differ according to the convertor design and the energy-containing end product produced. Anaerobic digestion to convert municipal solid waste to methane gas is still largely in the small-scale experimental stage, although some large-scale demonstration or "proof-of-concept" systems are under evaluation. Recovery of methane from landfills has reached a well-defined commercial level.

All of these processes were included within the scope of this project although some were emphasized more than others because of the greater amount of information available from pilot and full-scale operations.

Tests were restricted almost exclusively to process water--that water used directly for processing plant operating purposes--and resulting wastewater production. Water used for sanitary purposes

(restrooms, kitchen facilities, washrooms, showers, etc.) and for building air conditioning were not considered as process waters unless they were discharged to or otherwise became a part of a process water stream. Many facilities have a closed-loop cooling system of some type. These cooling systems are almost always designed and operated using conventional technology applied to cooling towers used for other industrial and power production purposes. The blowdown from cooling towers was therefore treated as an independent subject unless it became an integral part of the process water or wastewater streams, as for example when cooling tower blowdown was used for ash quenching.

Assessment of the water-related environmental control technology requirements at municipal solid waste-to-energy conversion facilities involved six basic steps:

1. Site visits to operating facilities including discussions with plant designers and operators;
 2. Review of existing water use and wastewater production practices and results from previous test work where available;
 3. Collection of samples of wastewater and solid residue from full-scale or pilot-scale operating facilities;
 4. Analysis of the treatability of the wastewaters that would be subject to direct discharge or discharge to municipal water pollution control plants;
 5. Assessment of the potential for producing harmful leachates upon land disposal or landfilling of waste solid residues;
- and

6. Identification of appropriate water pollution control methods for eliminating or minimizing adverse water-related impacts.

Descriptions of the facilities surveyed and summaries of the information collected and assessments made are contained in the following sections. It should be emphasized here that the purpose of the project described in this report did not include a comprehensive water sampling at each facility. All tests were conducted using limited numbers of samples collected at operating facilities or samples obtained from laboratory-scale tests. Therefore, all interpretations of the data presented should be made in this context.

1.2.1. Report Organization

This report is organized as follows: First, a summary of conclusions and recommendations provides concise statements of findings relative to water management and wastewater treatment of each of the four municipal solid waste-to-energy conversion categories investigated. Recommendations for specific treatments for each category are offered but represent only one or two of several possible suitable management or treatment schemes. Proper selection of specific treatment methods will depend on the local processing and residue disposal alternatives selected and the prevailing local environmental standards.

Second, Part II contains a brief description of each waste-to-energy facility visited during the subject survey showing points of water use and wastewater production. One or more facilities of each

type were selected for sampling of wastewaters and follow-up tests to determine requirements for water-related environmental controls. A comprehensive summary of the results of these tests is provided at the end of each section describing a specific waste-to-energy conversion method.

Detailed descriptions of these separate test programs and test results are contained in support documents available from the authors. A list of these reports is given in Appendix A.

1.3. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

1.3.1. Water Use Management

There is a need for improved water use management at municipal solid waste-to-energy conversion facilities. Designers should review carefully the interrelationship between water use and wastewater production at proposed projects. In many designs, water use can be reduced considerably and production of wastewaters often can be eliminated by using water for multiple purposes within a facility. For example, bearing cooling water and boiler or cooling tower blowdown often can be used for washdown, dust control, or for ash quenching. Wastewater streams could be segregated so that those subject to low contamination, as for example bearing cooling waters, are discharged to sanitary sewers, while those subject to greater contamination, such as cooling tower blowdown, can be used for ash quenching or sluicing.

Flow rates of individual water use streams should be monitored if they are involved directly in the processing of solid waste or energy production and particularly if they contribute to the production of a wastewater that will require special handling or treatment.

1.3.2. Water Quality and Treatment

1.3.2.1. Mass-Burning and Dry-Process RDF Facilities

Wastewaters associated with waste processing and storage at mass-burning and at dry-process refuse-derived fuel (RDF) facilities usually are produced infrequently and in small quantities--for example washdown and fire-fighting waters--or are essentially uncontaminated--as with

bearing cooling waters--so that they can be discharged to municipal sewerage systems without creating treatment problems at municipal wastewater treatment plants.

The major point of wastewater production is associated with ash quenching or sluicing and disposal in landfills in ash ponds. Some control of leaching from ash ponds and landfills almost certainly will be required to meet most state and federal rules and regulations. Leaching tests have shown that the constituents of major concern are total dissolved solids, chlorides, sulfates and heavy metals--especially cadmium, lead and zinc. These constituents present essentially the same disposal and environmental problems found when disposing of ash from conventional coal-fired power plants. Consequently, rules and regulations established for disposal of coal ash should apply to disposal of ash produced at mass-burning plants or at plants receiving and burning RDF. Use of well-planned and well-designed landfills is expected to provide satisfactory disposal of ash residues from most mass-burning and RDF-burning solid waste-to-energy conversion facilities. No organic priority pollutants that should restrict landfilling have been identified in leachates from these ash residues.

Ash quench waters and ash pond overflow can in most cases be collected and reused with minimal treatment required for control of solids carryover and neutralization of pH. Too little experience has been accumulated to answer questions related to corrosiveness of these recycled waters or to means of controlling corrosion if it does occur.

With proper design and water-use management practices, wastewater discharge (exclusive of cooling tower blowdown and sanitary wastes) can

be reduced to essentially zero. Excess quench waters can be discharged to municipal sanitary sewerage systems with little likelihood of causing adverse impacts at the municipal wastewater treatment plant if pretreatment regulations do not preclude such discharges.

Analysis of quench waters from the Nashville, Tennessee mass-burning plant indicated that discharge of the quench waters to the municipal sewer would, at the worst, cause a TDS concentration increase in the municipal wastewater of 1.7 mg/l and a total metals concentration increase of 0.034 mg/l. Neither of these concentration increases by themselves will cause adverse effects at biological treatment plants, but they will add to the amount of these constituents from other sources. Pretreatment regulations may preclude discharge to sanitary sewerage systems regardless of the lack of direct impact on municipal wastewater treatment plants.

At the present time, all water-related environmental concerns associated with mass-burning or dry-process RDF facilities can be satisfied by using available wastewater treatment technology, improved water use management and accepted landfilling practices.

1.3.2.2. Wet-Pulping

No opportunity was provided for assessing the need for wastewater treatment at wet-pulping facilities. Developers of this process stated that "there will be no wastewater discharge" from the processing facilities. Wastewater production associated with the burning of pulped RDF is expected to be essentially the same as for mass-burning and dry-process RDF facilities but analyses of these wastewaters should

be made before full-scale commercialization proceeds beyond the two plants now under construction.

1.3.2.3. Pyrolysis

Wastewaters produced by pyrolysis as typified by Union Carbide's PUROXTM process create the greatest potential for causing adverse environmental impacts because of their high organic content and the type of organic materials present. These wastewaters can, in most processes, be discharged to municipal wastewater treatment plants with little risk of causing adverse effects, but only because of the extremely high dilution ratio. The presence in relatively high concentrations of organic and inorganic priority pollutants may require that the wastewater be pretreated before discharge to a sanitary sewerage system. On-site biological processes can be used for this pretreatment but only if another wastewater, such as from municipal or industrial sources, is used to dilute the raw pyrolysis wastewater. The acceptability of this practice of pre-dilution for on-site treatment has not been established clearly in EPA or state rules and regulations. It does not appear that on-site biological treatment of wastewater from Union Carbide's PUROXTM or similar processes will produce an effluent suitable for discharge to a receiving stream.

There is also a question about whether some of the organic priority pollutants in pyrolysis wastewater actually are destroyed upon biological treatment or whether they are adsorbed on to biological solids and thus might cause restrictions to be placed upon disposal of the sludge produced.

It does not seem that activated carbon will provide treatment of PUROXTM pyrolysis wastewater to the extent that it can be discharged directly to a receiving stream. Activated carbon can be used for pre-treatment prior to discharge to a sanitary sewer but only at a premium in cost. There also is some question of the fate of inorganic and organic priority pollutants in the carbon regeneration process. Therefore, it seems that treatment of wastewaters from Union Carbide's PUROXTM pyrolysis process and disposal of sludges associated with these wastewaters will add significantly to the overall processing costs. While satisfactory wastewater treatment can be accomplished, the associated costs may impact heavily upon the commercial viability of the PUROXTM process. Minimal operating experience and lack of wastewater for conducting a treatability evaluation preclude drawing definite conclusions about the wastewater treatment requirements at other types of pyrolysis processes.

1.3.2.4. Biological Conversion

Recovery of methane gas from landfills seems to offer an economical means of recovering energy from municipal solid wastes. This practice generally has been restricted to old landfills; however, piping systems are being installed in some active fills for future methane recovery. The only source of wastewater in this process is the gas cleaning and drying operation and it is likely that this wastewater can be returned to the landfill, thereby causing little or no adverse environmental impact. However, further on-site test work is needed to verify this preliminary conclusion.

Water is used in anaerobic digestion processes to form a slurry so that the solids can be mixed and transported. Tests have shown that this digester liquor can be treated by conventional biological means when discharged to a municipal sewerage system. However, on-site treatment of the full-strength waste by either biological or chemical means will not produce an effluent that can be discharged directly to a surface stream. Therefore, landspreading seems to be the only feasible alternative for direct disposal. It should be pointed out that the need for such treatment and disposal is expected to be quite infrequent.

The major water-related concern is associated with the disposal of the solid residue removed by the slurry filtration process. This sludge or filter cake is about 50 to 70% moisture by weight and contains numerous materials that potentially can leach from the sludge after it is placed in a landfill. Tests have shown that most heavy metals seem to adhere tightly to the sludge solids and do not appear in leachates to any significant extent. Conventional pollutants such as COD, BOD and total and volatile dissolved solids are quite high. Therefore, leachate control will be an essential consideration in the design of landfills receiving the wet sludge residue from anaerobic digestion facilities.

Although definite conclusions must await successful continued operation of an anaerobic digestion unit, there seem to be no water-related problems that cannot be handled by using existing water pollution control technology. The major water-related impact will probably be the cost associated with these controls.

1.3.3. Costs

Estimated costs for water use management and wastewater treatment associated with the major classes of municipal solid waste-to-energy conversion process are summarized in Table 1. These estimates are subject to significant variation because of the inability to define specific wastewater treatment schemes for each waste-to-energy conversion method, lack of operating data of full-scale facilities, and the tentative status of many local, state and federal environmental control regulations. Also, the entire cost of residue handling and disposal should not be assigned to water-related treatment requirements because these solids would have to be collected, transported and disposed in any case.

In general, the economic impact of water-related environmental controls should not adversely affect the commercialization of mass-burning, dry-processed RDF or landfill gas recovery operations. Pyrolysis processes seem to be affected most severely by water-related control costs. Too little data are available to assess properly the economic impact of water-related controls at wet-pulped RDF and anaerobic digestion facilities.

1.3.4. Solid Waste Processing and Water Quality Standards

Neither the Clean Water Act of 1977 (Pub. L. 95-217) [5], amended Federal Water Pollution Control Act of 1972 (Pub. L. 92-500) [6], nor EPA rules and regulations specifically address the discharge of wastewaters from solid waste-to-energy conversion facilities. National

Table 1. Summary of costs for water-related environmental controls at municipal solid waste-to-energy conversion facilities.

Solid waste processing method	Water-related treatment option	Estimated wastewater treatment or disposal cost, \$/T _{sw}	Net typical waste-to-energy conversion cost, \$/T _{sw}	Increase in cost attributed to water-related controls, %
Mass-burning	a. Discharge of quench water to municipal sewer	0.003 to 0.01	12.00 ^a	<1
	b. Recycle of settled quench water (no blowdown treatment)	0.05 to 0.10	12.00	<1
	c. Recycle of settled quench water with blowdown treatment	0 to 0.02	12.00	<1/2
	d. Landfilling of ash	0.20 to 0.80	12.00	2 to 7
Refuse-derived fuel				
a. Dry processed	a. Unlined pond with minimum dredging	~0.30	16.00 ^b	~2
	b. Clay-lined pond with no ash removed and with sluice water recirculation	~0.75	16.00	~5
	c. Landfilling of ash	0.12 to 0.48	16.00	0.75 to 4
b. Wet-pulping	Unknown	Unknown	--	Unknown
Pyrolysis (Union Carbide's PUROX process only)	a. Carbon adsorption of raw wastewater	2.17 to 4.28	25.00 to 30.00 ^c (est)	9 to 14
	b. Carbon adsorption of biologically treated effluent (not including biological system costs)	2.41 to 4.78	25.00 to 30.00 (est)	10 to 16
	c. Discharge to municipal treatment facility (including sludge disposal)	0.88 to 1.76	25.00 to 30.00 (est)	3.5 to 6
Biological conversion				
a. Anaerobic digestion	a. Supernatant treatment	Unknown	--	Unknown
	b. Landfill of solid residue	0.50 to 2.0	20.00-25.00 ^d (est)	2.5 to 8
b. Methane recovery from landfill	Liquid treatment	0.10 \$/mill std cu ft of methane (min anticipated cost)	\$2.00 to 4.00/mill std cu ft of methane	2.5 to 5

^aBased on records from Nashville, Tennessee, facility.

^bBased on records from Ames, Iowa, facility.

^cBased on capital costs of \$100,000/TPD capacity at 8% interest for 20 yrs.

^dBased on capital costs of \$75,000/IPD capacity at 8% interest for 20 yrs.

discharge standards based on best available treatment (BAT) as directed by Pub. L. 92-500 [6] and Pub. L. 95-217 [5] have been set for a number of industrial categories (mean packing, pulp and paper, etc.), but to date no such standards have been established for solid waste processing / energy recovery facilities. The Clean Water Act of 1977 established a new industrial treatment-level category of "best conventional technology" (BCT) which industries must meet by July 1, 1984. To date, no guidelines for BCT have been established specifically for solid waste processing facilities, nor is it known how solid waste processing facilities will fit into this new classification.

Presently it seems that solid waste-to-energy conversion facilities should be placed in the same category as many other small industries. If there is to be direct discharge of a wastewater stream to a natural water body, it must meet all applicable receiving stream or discharge standards, but these standards vary from state to state. To date there is no major processing facility discharging a wastewater stream directly to a natural body of water; most plants presently in operation and producing a wastewater stream discharge to a sanitary sewerage system. Such industries must pretreat either to meet a sewer discharge standard set by the municipality or to remove all compounds not compatible with treatment of domestic wastewaters in municipal wastewater treatment plants. Noncompatible materials include those that are toxic to conventional biological treatment processes or otherwise interfere with treatment. Some chemicals cannot be removed by conventional municipal treatment processes and pass through essentially untouched or are adsorbed onto sludges and create problems with sludge disposal. Such

chemicals probably will be excluded or severely restricted by pretreatment standards from discharge to municipal sewerage systems.

In any case, local pretreatment standards, federal industrial category discharge standards, or toxic chemicals discharge standards established under authority of the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act of 1976 (Pub. L. 94 580) [3] will almost certainly cover disposal of liquid and solid residues and sludges produced from municipal solid waste-to-energy conversion facilities. At the present time, proposed industrial discharge standards are being evaluated through the public hearing process, and the outcome of these hearings is uncertain.

Ash residue from plants burning municipal solid wastes directly or co-fired as a refuse-derived fuel generally should be treated in the same manner as are ashes from coal-fired power plants. Most recent versions of EPA regulations state that fly-ash wastes, bottom-ash wastes, slag wastes and flue gas emission control wastes generated from the combustion of coal or other fossil fuels are exempt from the list of hazardous wastes [7]. Also RDF is exempt from the list of hazardous wastes. Therefore, utility ash residues produced upon direct-firing or co-firing of RDF should not be considered hazardous. However, disposal of utility and RDF waste residue must meet all applicable standards associated with solid waste disposal practices such as landfilling or landspreading. It is reasonable to expect that pretreatment standards for the proposed steam generation industrial category will apply to solid waste burning, but to date no standards have been published for this category.

Environmental impact statements were not available for any of the plants included in this present survey. Most facilities were developed and constructed without federal funds or were pilot or demonstration-scale systems, and no environmental impact statements were required. This will no doubt change in the future as more of these facilities are proposed for use across the nation and as concern for their environmental impact becomes more serious.

1.3.5. Water Use and Wastewater Production at Energy Conversion Subsystems

1.3.5.1. Air Pollution Control Equipment

Air pollution control equipment at energy conversion facilities, particularly those receiving refuse-derived fuel, can be a major source of water use and wastewater production. In general, wastewater from wet scrubbers is acidic. This is due to absorption of acidic constituents such as HCl, SO₂, SO₃, HF, CO₂ and organic acids from the flue gas. The concentrations of various constituents and the amount of wastewater produced will vary depending on recirculation and the type of system used. The trend in design seems to be toward use of dry electrostatic precipitators, which are more effective in reducing particulate matter. However, these units do not remove undesirable gaseous materials; and as air pollution control standards for gaseous components become more strict, wet scrubbers may have to be used either in conjunction with or in addition to more efficient processes for particulate control. Additional test work is needed to evaluate water-related environmental control technology requirements associated with scrubbers used on power plants receiving municipal solid wastes as a fuel source.

1.3.5.2. Cooling Systems

All power plants require some form of cooling system to condense steam for rerouting to boilers. Cooling towers with recirculated water are most often used for this purpose. A large body of knowledge is available on the subject of cooling towers, their water use requirements, and the associated water pollution control problems. These systems are usually closed-loop, and the cooling waters do not come into contact with the solid waste stream before, during, or after energy conversion. Processing of municipal solid waste for energy recovery then is not expected to change the amount of cooling water used, the quantity or character of the blowdown waters produced per unit of energy conversion, or the control technology required for treating these blowdown waters so that they will meet discharge or disposal standards.

PART II: RESULTS OF EVALUATION PROGRAM

2.1. MASS-BURNING FACILITIES

2.1.1. General Process Description

Mass-burning facilities involve placing unprocessed refuse directly into an incinerator, usually using traveling crane-type loaders which place the wastes into a feed hopper (Fig. 1). Mass-burning is used widely in Europe for incineration of municipal refuse with and without energy recovery. A number of mass-burning systems have been used successfully in large cities in the United States, but the majority of these facilities were built for volume reduction purposes and not for energy production. A list of the operational and planned mass-burning facilities designed for recovering energy from municipal solid wastes in the United States is contained in Table 2 [8,9].

Depending on the combination of burning and energy recovery processes utilized, water is required for air pollution control equipment, quenching incinerator residues, sluicing ash, cooling, lubrication, fire fighting, and miscellaneous housekeeping (which includes all use of water involved in cleaning any equipment or area of the plant). In most cases, the quality of water is not critical. This permits the use of sewage treatment plant effluents, seawater, and other nonpotable supplies although in most cases city water supplies or separate source supplies are used. The largest quantities of water are required for wet scrubber air pollution control units when this type of equipment is used and for quenching or sluicing of ash residues. Waterwall

Fig. 1. Schematic diagram of a typical mass-burning solid waste processing/energy recovery plant [10].

Table 2. Mass-burning energy conversion facilities in the U.S. [8,9].

Location	Owner	Capacity, TPD		Products	Start-up Date	Status
		Design	Operating			
Braintree, Massachusetts	City of Braintree	384	250	Steam	1971	Operational
City of Chicago	City of Chicago (Northwest)	1,600	1,200	Steam	1971	Operational
Harrisburg, Pennsylvania	City of Harrisburg	720 + 14 sludge	500	Steam	1972 (1979)	Operational
Nashville, Tennessee	Nashville Thermal Transfer Corp.	720	400	Steam	1974	Operational
Norfolk, Virginia	U.S. Naval Station	360	140	Steam	1967	Operational
Saugus, Massachusetts	RESCO	1,500	1,000	Steam, ferrous	1976	Operational
Oceanside, New York	Township of Hempstead, N.Y.	750	750	Steam, electricity	1974, (1976)	Operational
Portsmouth, Virginia	Norfolk Naval Shipyard	160	30	Steam	1976	Operational
Akron, Ohio	City of Akron	1,000		Steam, ferrous	1980	Shakedown early 1980
Hampton, Virginia	NASA, USAF	200		Steam	1980	Expected start-up late 1980
Glen Cove, New York	City of Glen Cove	225 + 25 sludge		Electricity	1981	Under construction 1980
Wilmington, Delaware	Delaware Solid Waste Authority; Ratheon Service Co.	1,000 + 50 sludge		Steam	1982	Under construction 1980
Dubuque, Iowa	Dubuque Metropolitan Area Solid Waste Agency	250		Steam, ferrous	1981	Under construction
Gallatin, Tennessee	Gallatin, Hendersonville, Sumner County Authority	150		Steam, electricity	1981	Advanced planning
North Andover, Massachusetts	Universal Oil Products, Inc.	3,000		Electricity	ND	Advanced planning
Beverly, Massachusetts	Industrial Development Financing Authority	591		Steam, electricity	ND	Advanced planning
Pinellas County, Florida	Pinellas County	2,000		Electricity, ferrous, non-ferrous	1982	Advanced planning
Westchester County, N.Y.	Contractor and Municipal Authority	1,500		Steam	1983	Advanced planning

incineration facilities can keep water use to a minimum when electrostatic precipitators and dry-handling systems for the ash are used, and this seems to be the trend in U.S. mass-burning systems.

There are basically two methods of residue quenching. The first consists of a series of water sprays that quench the residue as it drops from the incinerator. In the second method, residue from the incinerator drops into a water-filled quench tank. After quenching, the residue can be conveyed to trucks for final disposal or to other processing units for resource recovery. The bottom ash from mass-burning units seldom is sluiced because of the presence of large pieces that will not flow in a water stream. Water requirements for sluicing can be quite high. Quench waters often are discharged to sanitary sewer systems or to surface ponds. The recirculation of process water to decrease water usage and wastewater production is an approach used by some designers. These systems often require pH control or other chemical adjustment and occasional blowdown to control the levels of dissolved solids. Even with these precautions, corrosion and abrasion may occur because of soluble salt buildup.

Mass-burning operations usually have a large pit into which municipal refuse is dumped from collection trucks. This pit provides volume storage so that the incinerator can be operated continuously while refuse is deposited only during collection periods. Although no water is used intentionally in these pits, water brought in with wet wastes and water used to put out fires, which occur occasionally, can drain to the bottom of the pit. Some of the pits drain to the sanitary sewer. Others have no drain and depend on the refuse to soak up the water.

No measurements of the volumes or the quality of waters draining from these storage pits have been reported and no provisions have been made in full-scale plants for flow measuring or sampling for quality analysis. It is likely that the quantity of drainage is small, but it is possible that any drainage water which does reach the sewer will contain high concentrations of both inorganic and organic material.

2.1.1.1. Nashville Thermal Transfer Corporation

The Nashville incineration system has been in operation since June of 1974. The plant consists of two reciprocating grate waterwall incinerators, each rated at 360 tons per day (TPD) (Fig. 2). Steam produced in these units is used to heat a number of buildings in the central business district of Nashville and to power turbine-drive compressors that produce chilled water for cooling. The steam and chilled water distribution systems are separated for year-round heating as dictated by demand. Wet scrubbers for air pollution control were installed initially, but these units failed to meet air quality standards and produced large quantities of wastewater. Electrostatic precipitators have been installed to replace the wet scrubbers, and the fly ash is removed dry.

Refuse is delivered to the plant by publically and privately owned collection trucks. The truck contents are unloaded into a 5400 cubic yard storage pit. Refuse is removed from the storage pit by an overhead crane and dumped into the incinerator charging hoppers. Each charging hopper feeds the refuse into the connected incinerator.

The refuse is burned in the two reciprocating-grate four-level incinerators. Approximate retention time of the refuse in the incinera-

Fig. 2. Solid waste flow diagram for Nashville Thermal Transfer Corporation plant at Nashville, Tennessee.

tors is 20 minutes. Combustion air is introduced through openings above and below the grates. The movement of the grates creates continuous agitation which results in essentially complete combustion of the refuse. The forced draft fans that provide underfire air draw air from the storage pit area which helps control any odor problem.

Residue from the incinerators drops into a single ash hopper where it is spray-quenched with water. The wet residue is hauled to a landfill for final disposal. Ash from the electrostatic precipitators is handled dry and trucked to a landfill.

Water Use

Points of water use are shown in Fig. 3. All of the water used at the Nashville Thermal Transfer Facility is obtained from the city of Nashville, which takes water from the Cumberland River and treats it using coagulation, sedimentation, filtration, and chlorination.

Water is used to quench the residue as it falls from the incinerators into the ash hopper. This spray-quenching system requires about 14,400 gpd of water to cool the 80 TPD of residue or 3% of the total water used at the plant. About 85% of the water input is used for cooling throughout the plant. Water used for cooling the boiler water-condensers and the water jackets surrounding the incinerator charging hoppers is maintained in a closed-loop cooling system. Makeup water, obtained from the city, is phosphate treated and has algacides added. The makeup water rate is quite variable, depending on evaporation from the cooling tower, but averages about 350,000 gpd.

Water is also used to cool pumps, bearings, and air compressors in the plant. This is an open system with a total flow of approximately

Fig. 3. Water use flow diagram for the Nashville Thermal Transfer Corporation plant.

14,400 gpd. Figure 4 illustrates a typical point of bearing-cooling water usage at the plant.

An additional plant for treating the boiler feed water is located at the facility. This treatment consists of ion exchange softening and addition of chelating agents, sodium phosphate, and polyacrylate for corrosion and deposition control. The quantity of boiler makeup water is approximately 40,000 gpd or about 9% of the total water use. Chill-water makeup is approximately 11,520 gpd.

The other water uses are for firefighting and miscellaneous house-keeping. Fires occur infrequently and there are no metering devices on the firefighting equipment. No specific records are kept of the amounts of water used for plant cleanup.

Total water use is about 200 gpd per ton of refuse processed, exclusive of cooling tower use (Table 3).

Wastewater Production

Drainage from wet refuse in the storage pit enters a drainage system at the lower end of the sloped floor (Fig. 6). This system is connected to the sanitary sewers. Although wastewater flow from the storage pit is not measured, experience at other facilities having storage pits indicates that the amount of wastewater from this source is essentially negligible.

A portion of the quench water is absorbed by the incinerator residue. Excess water drains from the ash hopper into the trucks used to haul the residue to the landfill. Leakage from the ash hopper and from the trucks while they are sitting in "ash alley" (Fig. 5) flows to two

Fig. 4. Typical point of bearing-cooling water.

Fig. 5. Residue truck in ash alley.

Table 3. Water usage and wastewater production summary, Nashville Thermal Transfer Corporation [11].

Water use	Quantity used	
	Gallons/day	Gallons/ton ¹
Cooling tower makeup ²	350,000	875
Boiler water makeup	40,000	100
Chill water makeup ³	11,520	29
Quench water	14,400	36
Various plant cooling waters	14,400	36
Boiler feed pump cooling water	2,880	--
Air compressor cooling water	7,200	--
Boiler blowdown cooling water	4,320	--
Total	430,320	1,076
Total (without cooling tower)	80,320	201
<u>Wastewater Production</u>		
Cooling tower blowdown ²	70,000	175
Boiler blowdown	8,640	22
Quench water	14,400	36
Various plant cooling waters ⁴	14,400	36
Water seal on main condenser pressure relief valve	720	2
Total	108,160	271
Total (without cooling tower)	38,160	96

¹Based on 400 tons of solid waste processed per day.

²This quantity is highly variable.

³Seasonal use.

⁴Same breakdown as water use category.

Fig. 6 . Schematic diagram showing points of wastewater production at the Nashville Thermal Transfer Corporation plant.

surface drains at each side of the incinerator building. Additional leakage occurs while the trucks are en route to the landfill.

The surface drains are connected to the sanitary sewer system via an underground catch basin. Originally, the effluent from the wet scrubbers was discharged to these drains, but this action has been precluded by the installation of electrostatic precipitators.

Water used to cool pumps and bearings is directed to the sanitary sewer system. Figure 7 shows one point of bearing-cooling water discharge via floor drains. The total quantity of this cooling water is approximately 14,400 gpd or 36 gallons/ton (Table 3).

Occasional blowdown of water from the closed-loop cooling system is required. This blowdown comprises approximately 20% of the makeup water (Table 3). The total amount of makeup and blowdown depends on the heating/ cooling load through the plant and on the air temperature.

Boiler water blowdown to control the amount of solids in the boiler feed water goes to the sanitary sewer system. The quantity of blowdown is approximately 8,640 gpd but varies considerably with heating or cooling load and the amount of water lost to leakage in the steam piping system.

2.1.1.2. Saugus, Massachusetts

The RESCO North Shore Facility is a joint venture of Wheelabrator-Frye, Inc., and the De Matteo Construction Company. RESCO's incineration facility is located on the Saugus River just north of Boston, Massachusetts.

Refuse from incoming trucks is dumped into a 200-ft-long refuse pit. The pit has a maximum storage capacity of 6,700 tons. Two overhead

Fig. 7. Bearing-cooling water discharge.

head cranes feed the refuse into the furnace charging hoppers. Refuse is burned in two Von Roll type furnaces, each with a capacity of 750 TPD. The upper section of each furnace is made up of vertical waterwalls for the production of steam. The steam is sold to General Electric, which is located directly across the Saugus River from the RESCO facility.

Particulate matter is removed by a two-field electrostatic precipitator installed in the gas train of each furnace. An induced-draft fan discharges cleaned gases through a common concrete stack 178 ft high. The residue from each furnace drops into water-filled quench tanks and is then transported to a resource recovery building. The residue is processed through a trommel screen for removal of bulky material. It is then magnetically separated for ferrous recovery. The remaining bulky and nonferrous material is transported to a landfill.

Boiler makeup water is purchased from the town of Saugus and is demineralized on site. Originally, steam condensate was to be returned from General Electric Co. via a 3,000 ft pipeline, but too little condensate is captured, and its quality is not suitable for recycling. Therefore, all steam is produced from new water.

Boiler feed water is used as a cooling water for the boiler feed jacket and ash discharge chutes before going to demineralizers for treatment. This reduces considerably the amount of water that otherwise would have to be discharged.

Ash quench water is recirculated indefinitely, and water lost with the ash is made up from bearing-cooling water and demineralizer backwash water. These waters are neutralized when necessary using caustic or acidic agents. Plant management has indicated that, except for

emergency situations when blowdown from the quench tank is required for maintenance or cleaning, there is no discharge of wastewater to the sewer system (other than sanitary wastes).

2.1.2. Wastewater Quality and Treatment at Mass-Burning Facilities

2.1.2.1. Ash Quenching

Wastewater production associated with ash quenching is of greatest concern at mass-burning energy recovery systems. Because of small volumes and lack of contact with materials that would cause treatment problems, water from other sources--such as bearing cooling waters and boiler blowdowns--can be discharged to sanitary sewer systems with little or no concern about causing adverse environmental impacts. Ideally these wastewaters will be collected and used for ash quenching, thereby reducing water consumption and wastewater production.

The quality of the ash quench waters can be expected to be highly variable because of the changing nature of the ash and the manner in which the ash is wetted with each quenching operation. Generally, however, wastewaters draining from ash quenching operations not using recycled quench water can be expected to have a composition similar to that shown in Table 4. The particulate matter in the wastewater stream settles well, leaving a clarified effluent with reduced metal concentrations (Table 4).

The reduction in municipal wastewater quality caused by discharging either treated or untreated quench water is very small and is not expected to preclude discharge to a municipal biological treatment plant.

Table 4. Composition of ash quench water from mass-burning facilities.

Constituent	Quench water quality						Water quality standards, mg/l			Constit- uents of concern
	Unsettled			Settled			Direct discharge ^b	Industrial pretreatment ^c	Toxic threshold ^d	
	mg/l	mg/g	mg/l in W.W. ^a	mg/l	mg/g	mg/l in W.W. ^a				
CONVENTIONAL POLLUTANTS										
Chemical oxygen demand	--	--	--	--	--	--	>200 ^f	N	N	
Biochemical oxygen demand	<u>292</u>	0.58	0.56	<u>268</u>	0.54	0.51	<u>10-30</u>	>300 ^f	N	*
Suspended solids	<u>1364</u>	2.74	2.62	<u>352</u>	0.70	0.68	<u>10-30</u>	>300 ^f	N	*
Total dissolved solids	<u>776</u>	1.55	1.49	<u>908</u>	1.82	1.74	<u>500</u> ^f	N	50,000 ^f	*
Volatile dissolved solids	296	0.59	0.57	296	0.59	0.57	N ^e	N	N	
Alkalinity	824	1.65	1.58	548	1.10	1.05	N	N	N	
Calcium	440	0.88	0.84	304	0.61	0.58	N	N	N	
Magnesium	23	0.05	0.04	8	0.02	0.02	N	N	N	
Sodium	39	0.08	0.07	39	0.08	0.07	N	N	N	
Potassium	92	0.18	0.18	92	0.18	0.18	N	N	N	
Chloride	108	0.22	0.21	108	0.22	0.21	250 ^f	N	25,000 ^f	
Sulfate	208	0.42	0.40	208	0.42	0.40	250 ^f	N	25,000 ^f	
Fluoride	<0.4	0.001	0	<0.4	0.001	0	1.4-2.4	N	140-240	
Nitrite + nitrate	0.8	0.002	0	0.88	0.002	0	10 ^f	N	10,000 ^f	
Total Kjeldal nitrogen	19	0.04	0.04	13	0.03	0.02	N	N	N	
Ammonia nitrogen	0.14			0.12			N	N	N	
Total phosphate	48	0.10	0.09	21	0.04	0.04	N	N	N	
Iron	<u>24</u>	0.05	0.05	<u>6</u>	0.01	0.01	<u>0.3</u> ^f	N	30	*
Manganese	2.2	0.004	0	0.6	0.001	0	0.05 ^f	N	5	*

Table 4. Continued.

Constituent	Quench water quality						Water quality standards, mg/l			Constit- uents of concern
	Unsettled			Settled			Direct discharge ^b	Industrial pretreatment ^c	Toxic threshold ^d	
	mg/l	µg/g	µg/l in W.W. ^a	mg/l	µg/g	µg/l in W.W. ^a				
HEAVY METALS										
Arsenic	0.022	0.04	0.04	0.01	0.02	0.02	0.05	<1.0	50	
Barium	0.20	0.40	0.38	0.20	0.40	0.38	1.0	<2.5	100	
Cadmium	<u>0.12</u>	0.24	0.23	<u>0.04</u>	0.08	0.08	<u>0.01</u>	<3.0	1	*
Chromium	0.16	0.32	0.31	0.08	0.16	0.15	0.05	<8.0 total <0.05 (hex)	5	
Lead	<u>5.12</u>	10.24	9.83	<u>1.56</u>	3.12	3.00	<u>0.05</u>	<3.0	5	*
Mercury	<u>0.031</u>	0.06	0.06	<u>0.0136</u>	0.03	0.03	<u>0.002</u>	<0.1	0.2	*
Selenium	<0.0024	0	~0	<0.0024	~0	~0	0.01	<1.0	1	
Silver	0.04	0.08	0.08	0.024	0.05	~0	0.05	<1.0	5	
Copper	0.80	1.6	1.54	0.44	0.88	0.84	1.0	<6.0	100	
Zinc	<u>11.3</u>	22.6	21.7	3.2	6.40	6.14	<u>5.0</u>	<8.0	500	*
PESTICIDES (No pesticides, PCB's or organic priority pollutants found present)										

^a mg/l in combined wastewater if quench water is discharged to sanitary sewer. (µg/l in w.w. = $1.92 \times 10^{-3} \times$ mg/l in quench water)

^b Based on equivalency to Safe Drinking Water Act or Clean Water Act standards.

^c Based on typical municipal standards throughout U.S.

^d Based on limits for toxicity as established or proposed by EPA under authority of RCRA.

^e N = no specific standards established.

^f Tentative or anticipated standard [14].

as indicated by the relatively high industrial pretreatment standards (Table 4). The heavy metals carryover, however, will add to the total from other sources. These metals are likely to be adsorbed onto wastewater sludge particles and will contribute slightly to the metals content of the sludge. This load will have to be considered in evaluating sludge disposal alternatives.

No organic priority pollutants were isolated from the ash quench water or upon direct extraction from the ash residue.

Discharge of ash quench waters directly to a stream or to storm sewers is not expected to be a permissible disposal practice. The presence of unburned organic solids causes the BOD to be above acceptable discharge levels (Table 4). This high BOD would require that the ash quench waters be treated biologically or with activated carbon prior to direct discharge to a receiving stream. The suspended solids concentrations also are too high for direct discharge even with settling. In some cases a polymer can be used to enhance settling and improve the suspended solids removal, but this is not expected to produce a quality suitable for direct discharge and filtration or equivalent treatment may be required.

Concentrations of pollutants in the ash quench water will increase as the amount of recycle is increased. The extent of this increase will be controlled by makeup requirements and by the solubility of each constituent. Although it is not possible to determine the exact increase in concentration, the total mass of each constituent can be expected to decrease with increased recycle because of the reduced amount of water wasted. It is expected that the Nashville data represent a worst-case

situation (in terms of mass leaching) because of the once-through use of quench water. The Saugus plant represents the other extreme where no quench water is discharged routinely to a sewer.

Therefore, it seems that a minimum treatment prior to direct discharge of ash quench waters to a receiving stream will be solids separation, heavy metals removal and biological or other treatment to reduce the organic content to acceptable levels.

When quench waters are recycled, the minimum treatment will be solids separation with occasional blowdown to a sanitary sewer to control salt buildup. If pretreatment standards are in effect and applicable to quench water discharge, addition of chemical precipitation units may be required to control the discharge of heavy metals.

One problem of concern with respect to plant design and operation is the possibility of corrosion occurring when quench waters are recycled. No problems have been reported at the Saugus plant but some coal-burning plants have had to use dilution of bottom-ash sluice waters that were recirculated and in some cases have added polyphosphates and acrylates to reduce scaling caused by calcium sulfate [12].

2.1.2.2. Ash Disposal

Disposal of fly ash and bottom ash from power plants has been addressed by the U.S. EPA under authority of the Resource Conservation and Recovery Act of 1976. Presently, no specific restrictions on landfill disposal have been established except that normal sanitary landfill practice and design criteria must be followed. However, some states, such as Florida, have established more strict criteria for ash disposal [13].

The primary concern is that heavy metals and soluble salts, which are concentrated in the ash will leach from the landfilled residues and cause contamination of groundwater resources. This requires careful consideration with respect to landfill site selection, design and operation.

The proposed criteria established by EPA under authority of RCRA (PL 94-580) indicate that

"A facility or practice shall not contaminate an underground drinking water source beyond the solid waste boundary or beyond an alternative boundary--that would result in contamination of groundwater which may be needed or used for human consumption--(so that) the concentration of that substance in the groundwater exceeds the maximum contaminant level (MCL) specified in [Table 5]." [14]

Analysis of data from leaching tests using ash from the Nashville plant suggests that the constituents of major concern are total dissolved solids, chlorides and sulfates (Table 5) [15]. These are conventional pollutants and, while causing no major emergency health problems, may require that leachates be collected and treated prior to disposal. Otherwise, landfills will have to be designed for essentially total containment of leachate. With the exception of organic content (as indicated by COD), the type and concentration of materials in the leachate are not greatly different from those in leachates from ashes produced at coal-burning power plants (Table 5). Therefore the question of leachate quality should not constitute any greater limiting factor in developing and using mass-burning facilities than occurs with coal-burning power plants. Although coal ash leachate often has been shown to contain phenols and polyaromatic hydrocarbons, none were found in the leachate samples analyzed for this project (Table 5).

Table 5. Concentration of contaminants in leachates from ashes produced at mass-burning facilities.

Constituent	Nashville ash leachate			City of Philadelphia	Conventional coal ash leachate, mg/l			Water quality standards		
	Conc., mg/l		Total leachable	Incinerator ash leachate [16]	(Ref 17)	Ames power plant [18]		Limits to ground-water ^a (MCL) mg/l	Toxic waste threshold, ^b mg/l	Constituents of concern
	Peak	Average	mg/g	mg/l		Bottom ash	Fly ash			
CONVENTIONAL POLLUTANTS										
Chemical oxygen demand	<u>720</u>	83	1.3-5.3	1320-12,090	<30 ^c	8-11	4-9	N ^d	N	
Biochemical oxygen demand	<u>455</u>	108	3.3-5.3	--		1.6-1.7	0.9-12	N	N	
Suspended solids	--	--	--	--		--	--	N	N	
Total dissolved solids	<u>6579</u>	<u>763</u>	17-44	--		533-593	1389-1687	<u>500</u> ^e	50,000 ^e	*
Volatile dissolved solids	1504	310	3.7-8.7	--		90-115	108-129	N	N	
Alkalinity	633	75	1.8-4.2	204-911		19-75	90-1302	N	N	
Calcium	--	--	--	343-733	192-696	--	--	N	N	
Magnesium	--	--	--	--	4.8-53	--	--	N	N	
Sodium	--	--	--	50-525		--	--	N	N	
Potassium	--	--	--	34-361		--	--	N	N	
Chloride	<u>3114</u>	219	0.7-16.8	13-1135	<1-2	38-44	26-29	<u>250</u> ^e	25,000 ^e	*
Sulfate	<u>3430</u>	69	1.2-4.3	184-374	457-489	238-257	--635	<u>250</u> ^e	25,000 ^e	*
Fluoride	0.65	0.41	0.003-0.03	0.02-0.10	<1.0	0.51-0.70	0.38-0.70	1.4-2.4	140-240	
Nitrite + nitrate	2.15	0.25	0.01	--	<1.0	0.07	0.02-0.05	10 ^e	1,000 ^e	
Total Kjeldal nitrogen	63	4.30	0.10-0.25	--		0.89-0.93	0.38-1.27	N	N	
Ammonia nitrogen	13.6	0.50	0.02	5.3-21.7		0.63-0.69	0.70-0.78	N	N	
Total phosphate	9.3	0.75	0.01-0.05	--	<1.0	0.14-0.31	0.04-0.11	N	N	
Iron	--	--	--	<u>0.35-5.38</u>	0.02-1.0	<u>7.5</u>	--	<u>0.3</u> ^e	30 ^e	*
Manganese	--	--	--	--	0.01-3.0	0.31	--	<u>0.05</u> ^e	5 ^e	?

Table 5. Continued.

Constituent	Nashville ash leachate			City of Philadelphia	Conventional coal ash leachate, mg/l			Water quality standards		Constit- uents of concern
	Conc., mg/l		Total leachable	Incinerator ash leachate [16] mg/l	Ames power plant [18]		Limits to ground-water ^a (MCL) mg/l	Toxic waste threshold, ^b mg/l		
	Peak	Average	mg/g		(Ref 17)	Bottom ash			Fly ash	
INORGANIC PRIORITY POLLUTANTS										
Arsenic	0.0002	0.0001	4x10 ⁻⁶	--	0.065-0.174	0.007	<0.0005	0.05	5	
Barium	0.10	0.050	0.002	--	<1.0	0.50	0.70	1.0	100	
Cadmium	<u>0.38</u>	0.042	2.0-31.5x10 ⁻⁴	--	0.005-0.01	<0.006	<0.006	0.01	1	*
Chromium	0	0	0	--	<0.02	0.02	0.01	0.05	5	
Lead	<u>0.46</u>	0.041	7-25.7x10 ⁻⁴	--	<0.04	<u>0.050</u>	0.050	<u>0.05</u>	5	*
Mercury	0	0	0	--	0.0006-0.0009	0.0005	0.0005	0.002	0.2	
Selenium	0.0004	0.0002	8x10 ⁻⁶	--	0.02-0.03	<0.0007	<0.0007	0.01	1	
Silver	0	0	0	--	<0.02-0.04	0.010	<0.007	0.05	5	
Copper	--	--	--	--	<0.01	0.093	0.020	1.0	100	
Zinc	--	--	--	--	<1-2.0	1.66	0.38	5.0	500	
Boron	--	--	--	--	5-25	--	--	--	--	

PESTICIDES

(No pesticides, PCB's or organic priority pollutants found present)

^aBased on limits established or proposed by EPA under authority of RCRA or assumed equivalency to Safe Drinking Water Act standards.^bBased on limits for toxicity as established or proposed by EPA under authority of RCRA.^cCOD = TOC x 3^dN = no specific standards established.^eTentative or anticipated standard [14].

2.1.3. Water Use Management at Mass-Burning Facilities

Well-planned water use management can reduce wastewater production and treatment requirements at mass-burning facilities. In most plants, cooling tower blowdown, boiler blowdown and bearing-cooling waters can be used for ash quenching. Collection and retention of ash quench waters permit their reuse. The experience at the Saugus plant, where essentially no wastewater is discharged, is ideal; but this operation is somewhat atypical because of the absence of cooling tower blowdown. If cooling tower blowdown waters can be discharged to a municipal sewer, complete retention of ash quench waters with no wastewater discharge seems possible. The only wastewater leaving the facility is then that with the quenched ash. Even in this case, considerable amounts of cooling tower blowdown can be used for ash quenching, thereby reducing water consumption and the amount of cooling tower blowdown going to sewers or to on-site treatment.

2.1.4. Costs of Wastewater Treatment and Ash Disposal at Mass-Burning Facilities

Costs for treatment of ash quench waters or for landfilling of ash residues are difficult to determine accurately because of site-specific considerations at each facility and because most facilities do not keep records in sufficient detail to determine costs attributable to ash quenching and disposal. Reasonable estimates can be made using costs for various levels of treatment as shown in Table 6.

Table 6. Estimated costs for water-related environmental controls associated with mass-burning of municipal solid waste for energy recovery.

Treatment option or level	Wastewater production, gal/ton	Treatment or disposal cost	
		Unit cost	\$/T _{sw}
Discharge of quench water to municipal sewer	10 to 50 (exclusive of cooling tower water)	0.15 to 0.50 ^a \$/1000 gal	0.003 to 0.010
Recycle of settled quench water (no blowdown)	10 to 20 (recirculated)	0.5 to 1.00 ^b \$/1000 gal	0.05 to 0.10
Recycle of settled quench water with blowdown treatment	10 to 20 (recirculated)	0.5 to 1.00 ^b \$/1000 gal	0.005 to 0.02
	0 to 10 (treated)	0.15 to 0.50 ^b \$/1000 gal	0 to 0.005
Landfilling of ash	--	1.00 to 4.00 \$/T _{ash}	0.20 to 0.80

^aIncludes no additional capital costs at treatment plant.

^bIncludes equipment and operation.

The total cost for recycling excess ash quench water and landfilling residual ash agrees fairly well with the \$0.63/ton of coal for pond disposal of coal and RDF ash reported for the Ames, Iowa, plant [19].

2.2. MECHANICAL PROCESSING FOR SUPPLEMENTAL FUEL PRODUCTION

2.2.1. Dry Processing for Production of Refuse-Derived Fuel

Some types of furnaces require that municipal refuse be shredded or otherwise pulverized and used as a supplemental fuel for co-combustion in gas, oil, or coal-fired boilers. Among these are the tangential or suspension fired, traveling grate and spreader stoker boilers, fluidized-bed reactors and some pyrolysis units. Very finely divided refuse can be blended with oil for use in oil-fired furnaces. Stoker-fired or traveling grate coal-fired furnaces can accept coarsely ground municipal refuse. Mechanical processing plants usually involve single- or two-stage grinding, ferrous metals separation, and air classification to separate the light burnable fraction from the sand, glass and other heavy nonburnable materials (Fig. 8). Further separation of the heavy fraction can produce aluminum and glass cullet. Storage pits may be used ahead of the plant or the shredded burnable material may be stored after mechanical processing. A list of the dry-processing, refuse-derived fuel plants in the United States is given in Table 7.

Of the four categories of solid waste processing facilities surveyed, mechanical (dry) processing for supplemental fuel production requires the least amount of water. This occurs because little water is used to produce the refuse-derived fuel and because water used at the RDF consuming plant usually is not included as process water. The primary uses of water are for dust control, firefighting and clean-up activities. Water occasionally is used in some types of materials

Fig. 8. Flow diagram of a solid waste processing plant designed to produce refuse-derived fuel for energy recovery (St. Louis, Mo.) [20].

Table 7. Refuse-derived fuel plants in the U.S. [8,9].

Location	Owner	Capacity, TPD		Products	Start-up Date	Status
		Design	Operating			
Ames, Iowa	City of Ames, Iowa	200	170	RDF, ferrous	1975	Operational
Baltimore Co., Maryland	Maryland Environmental Service	1,200	750	RDF, ferrous	1976	Operational
Chicago, Illinois	City of Chicago	1,000	500	RDF, ferrous	--	Plant is currently undergoing shakedown (1980)
East Bridgewater, Massachusetts	Combustion Equipment Associates	160	160	ECO-FUEL II TM	1973	Operational
Lane County, Oregon	Lane County	500	--	RDF, ferrous	--	Under construction
Milwaukee, Wisconsin	Americology Div. of American Can Co.	1,200	900	RDF, bundled paper, ferrous, aluminum, glass concentrate	--	Plant is currently undergoing shakedown (1980)
St. Louis, Missouri	Union Electric Company	150-300	--	RDF, ferrous	1972	Demonstration facility is now closed. Union Electric has abandoned its work in solid waste utilization due to local problems.
Madison, Wisconsin	City of Madison	400	200	RDF, ferrous	1979	Operational
Albany, New York	City of Albany	750	--	RDF, ferrous	1980	Under construction
Bridgeport, Connecticut	Connecticut Resources Recovery Authority	1,800	--	ECO-FUEL II TM ferrous, aluminum, glass	1979	In start-up phases
Monroe County, New York	Monroe County	2,000	--	RDF, ferrous, aluminum, glass	1979	Shakedown
Niagra Falls, New York	Hooker Chemicals and Plastics Corp.	2,286	--	Steam, electricity, ferrous	1980	Under construction
Appleton, Wisconsin	Sadoff and Rudoy Industry	2,400	--	Steam, ferrous	1982	Advanced planning
Columbus, Ohio	City of Columbus	1,200	--	Electricity, ferrous	1981	Processing operational; generating plant in planning
Lakeland, Florida	City of Lakeland; Orlando Utilities Comm.	300	--	Electricity, ferrous	1981	Under construction

Table 7. Continued.

Location	Owner	Capacity, TPD		Products	Start-up Date	Status
		Design	Operating			
Newark, New Jersey	Combustion Engineering Assoc.; Occidental Resources Recovery Assoc.	2,000	--	RDF, ferrous, aluminum, glass	1981	Advanced planning
Norfolk, Virginia (SE Vir. Plan. Auth.)	Southeastern Public Service Authority	2,000	--	RDF, electricity	1983	Advanced planning
Detroit, Michigan	City of Detroit	3,000	--	RDF, steam	1983	Advanced planning
Peabody, Massachusetts	Combustion Engineering Assoc. Inc.	1,800	--	RDF, ferrous	no	Advanced planning
Tulsa, Oklahoma	Tulsa Energy Resources Recovery Authority	1,000	--	RDF, ferrous	1982	Advanced planning

separation units, such as those for recovering aluminum and glass for cooling purposes.

Wastewater streams originate from washdown operations, drainage from tipping floors, and materials recovery processes. In most cases, these wastewaters are discharged to sanitary sewers. When refuse-derived-fuels are burned in electrical generating facilities the increased ash content can cause an increase in the amount of water used for ash quenching and sluicing. An associated increase in wastewater production often occurs.

2.2.1.1. Ames, Iowa

The Ames, Iowa, Solid Waste Recovery System currently operates eight hours a day, five days a week and processes approximately 100 to 150 TPD of solid waste. It has one process line with two-stage shredding, ferrous removal, air classification, and various noncombustible processing units including a trommel screen and an aluminum recovery system. Dust control equipment consisting of a bag-house filter was installed in 1978. The refuse-derived fuel produced at the plant is pneumatically conveyed to an Atlas storage bin and from there is conveyed to the Ames Municipal Power Plant where it is blended with coal and burned in either of three furnaces. Two of the furnaces are of the traveling-grate type and the third is a tangentially-fired suspension unit. The flow of solid waste through the plant is shown in Fig. 9.

Water Use

The primary use of water in the process building includes occasional washdown of the tipping floor and dust-control using sprayers in each of the shredders and over the conveyers at the discharge of the shredders.

SOLID WASTE FLOW DIAGRAM
AMES REFUSE DERIVED FUEL PLANT
AMES, IOWA

Fig. 9. Solid waste flow diagram for the Ames, Iowa, refuse-derived fuel plant.

The spray nozzles in the shredders distribute water at a rate of about 7200 gpd. This water is absorbed by the refuse. No records are kept on the amount of water used for plant washdown. Fire protection facilities include nine hose bibs located throughout the processing area and three fire hose racks. Fires occur infrequently and no measurements of the specific quantities of water used for fire control are recorded.

Uses of water other than in the processing area include a ten-ton air conditioning unit with water-cooled condenser; a locker room with shower, toilets, and sinks; a washing machine used to clean approximately two loads of uniforms per day; lawn sprinkling; and cleanup of driveways and parking lots. Only the total water usage at the plant, which includes all the above uses of water, is metered. A monthly tabulation of water usage for one year of operation is given in Fig. 10. The low water use in January 1977 reflects the effect of adding a new metering valve to the air conditioning system. Points of water use in the processing plant are shown in Fig. 11. Water used in the plant is lime-softened groundwater obtained from the City of Ames.

Other water is used at the power plant to sluice the residue from the tangentially-fired suspension furnace and the electrostatic precipitator to a nearby settling pond. The water for sluicing is untreated and is obtained from wells which are not used by the City of Ames. The increased amounts of ash from burning the RDF has caused an increase in the amount of water used for sluicing. The amount of water used varies with the amount and composition of the ash but ranges from about 250,000 to 300,000 gpd.

Fig. 1C. Monthly water usage compared to the amount of solid waste processed at the Ames, Iowa Solid Waste Recovery System.

Fig. 11. Water use flow diagram for the Ames, Iowa refuse-derived fuel plant.

Wastewater Production

Points of wastewater production are shown in Fig. 12. Water draining from wet refuse, from firefighting, and from washdown on the tipping floor flows into drains that are connected to the sanitary sewer. There are no flow or quality measurements made of this stream, but the drainage and washdown waters entering the sanitary sewer from the tipping floor represent small quantities relative to total sewage flow. There is a possibility, however, that hazardous chemicals falling on the tipping floor can accidentally be washed down the sewer and cause problems at the municipal wastewater plant. Care in monitoring incoming wastes should reduce the risk of this type of problem occurring.

Sluice water used to remove bottom ash and fly ash from the power plant is directed to settling ponds where a large portion of the sluice water seeps into the ground or flows without monitoring into the Skunk River.

2.2.1.2. Chicago, Illinois

The Chicago Southwest Supplementary Fuel Processing Plant is located on 4½ acres of land owned by the City of Chicago at West Thirty-Fourth Street and South Hamlin Avenue. The Commonwealth Edison Power Plant, to which the processing plant will supply supplementary fuel, is located several hundred yards from the processing plant. This fuel processing plant is sized to process 1000 TPD of solid waste. About 35 full-time personnel will be required to operate the plant 16 hours/day, 5 days/week.

Refuse is unloaded from collection vehicles onto a 50,000 sq ft fully enclosed tipping floor (Fig. 13). Front-end loaders push the refuse into a primary shredder feed-conveyor pit. Refuse is reduced in

Fig. 12. Wastewater flow diagram for the Ames, Iowa refuse-derived fuel plant.

Fig. 13. Solid waste flow diagram for the Southwest Supplementary Fuel Processing Facility at Chicago, Illinois.

size to approximately 8 in. by the coarse shredder and discharged onto an elevating belt conveyor which transports the shredded refuse to an air classifier. The air classifier separates the shredded material into light and heavy fractions. The "heavies" are transported by a conveyor to the magnetic separator where ferrous material is removed. Remaining nonferrous material is hauled to a landfill for final disposal. The light fraction drops from the air classifier into the fine shredder for reduction to a $1\frac{1}{2}$ in. size. This fine-shredded material is then pneumatically conveyed several hundred yards to two Atlas storage bins located at the Commonwealth Edison Power Plant. The two processing lines are basically identical, with every major piece of equipment duplicated all the way to the storage bins.

The major difference between this plant and other operational RDF plants is an extensive dust collection system. Beginning with the large dust loads over both infeed conveyors and continuing all the way through the processing area with its enclosed conveyors, dust is collected and blown through a series of cyclones and baghouses located outside the building and behind the processing area. Once collected, the dust is mixed with the RDF prior to transport to the storage bins.

Water Use

The only uses of water at the processing plant are for fire control and miscellaneous housekeeping. Anticipated points of water usage are shown in Fig. 14.

Wastewater Production

The only source of wastewater at the processing plant is from the tipping floor. Water from wet refuse, firefighting, and washdown of

Fig. 14. Water use flow diagram for the Southwest Supplementary Fuel Processing Facility at Chicago, Illinois.

the tipping floor will flow into a system of peripheral floor drains. The wastewater is drained to a settling basin (6 ft x 18 ft x 12 ft) located between the two processing lines in the processing area. Here the skimmings and sludge are removed and conveyed to the primary shredder. The effluent from the settling basin will be discharged into the sanitary sewer system. The wastewater production diagram is shown in Fig. 15. At the time of this investigation, there was too little operating experience at the Chicago facility to provide an accurate indication of the quantity and quality of this wastewater.

2.2.1.3. Milwaukee, Wisconsin

The Americology Solid Waste Recycling Plant is located across from Marquette University on a nine-acre site adjacent to the Menomonee River. The plant operates one shift per day, five days a week. It has two processing lines that are virtually identical, with the only difference being that one line has a trommel screen and glass washing process, whereas the other line uses a vibrating screen for non-combustible/nonferrous separation (Fig. 16). Refuse-derived fuel is conveyed to a compactor and then is hauled to the Oak Creek Power Plant where it is blended with coal and burned to produce electrical energy.

Water Use

The primary use of water in the processing area is for the glass washing station, although water can be added almost anywhere in the two lines--at shredders, classifiers, etc. (Fig. 17). This capability exists primarily for fire and dust control and its use is kept to a minimum. There is also a sprinkler system for fire control above the tipping floor and over the two infeed conveyors.

Fig. 15. Wastewater flow diagram at the Southwest Supplementary Fuel Processing Facility at Chicago, Illinois.

Fig. 16. Solid waste flow diagram for the Americology resource and energy recovery facility at Milwaukee, Wisconsin.

City water is used for cooling all the shredders and air classifiers and the aluminum recovery system and then is directed to the glass washing station. The calculated water usage for process equipment is about 300,000 gpd during normal operation. This does not include the water used for firefighting and for the sprinkler system.

Wastewater Production

There are two sources of wastewater at the processing plant (Fig. 18). The first source is the tipping floor. There are no drains on the tipping floor, and any excess water flows to drains located beneath the two infeed conveyors. The other source is the glass washing station. The glass washing unit uses cooling water from other equipment to clean the glass aggregate. Both of these streams flow to the sanitary sewer system. There are no measurements of the flow rates or quality of these streams.

2.2.1.4. Baltimore County, Maryland

The Baltimore County Solid Waste Disposal System and Reclamation Project began operation in March 1976. The plant has two processing lines, each sized to process 50 tons/hour of solid waste. Each line includes shredding, magnetic separation, two-stage air classification, and secondary materials recovery. The most identifying feature is the use of two movable bridges over push-pits for unloading. The solid waste flow diagram is shown in Fig. 19. There is no information on water use and wastewater production at the plant. In response to correspondence, the Director of Product Planning for Teledyne National stated that "the entire operation features dry separation and recovery. There is no water effluent" [21].

Fig. 18. Schematic diagram showing points of wastewater production at the Americology resource and energy recovery facility at Milwaukee, Wisconsin.

Fig. 19. Solid waste flow diagram for the refuse-derived fuel processing and resource recovery plant at Baltimore County, Maryland.

2.2.1.5. East Bridgewater, Massachusetts

The Combustion Equipment Associates ECOFUEL IITM processing plant located at Brockton, Massachusetts, began operation in October 1973. The plant currently is operated 12 hours a day, 5 days a week, and has the capacity to process 800 TPD of solid waste. The processing plant consists of shredding, trommel screening, magnetic separation, air classification, secondary screening, ball milling, and product sizing (Fig. 20). The product, ECO-FUEL IITM, contains the organic fraction of the solid waste which has been processed to a fine powder of controlled particle size. This fuel can be used in a variety of ways--for direct firing in boilers, for slurring in oils, or for pyrolysis. ECOFUEL IITM is stored in silos on site and is transported by truck to contract customers.

Water Use

Water is added to the ball mill at a maximum rate of 8640 gpd to simulate input heat load when operating at less than full capacity; none is required at full capacity (Fig. 21). This water is evaporated in the fuel drying process. Another 3000 to 4000 gpd of water is used to cool bearings. Some water is used to dilute the ECO-FUEL IITM additive, although this is eventually evaporated.

Wastewater Production

Bearing-cooling water is discharged to the sanitary sewer system (Fig. 22). The flow rate of this stream is about 3000 to 4000 gpd. Sanitary drainage of toilet fixtures and water used to clean the refuse tipping floor and dumping areas are drained to a settling basin for

Fig. 20. Solid waste flow diagram for the Combustion Equipment Associates ECO-FUEL II plant at East Bridgewater, Massachusetts.

Fig. 21. Schematic diagram showing points of water use at the Combustion Equipment Associates ECO-FUEL II plant at East Bridgewater, Massachusetts.

Fig. 22. Schematic diagram showing points of wastewater production at the Combustion Equipment Associates Plant at East Bridgewater, Massachusetts.

neutralization prior to discharge into the sanitary sewer. There are no flow measurements of this stream.

2.2.1.6. Wastewater Treatment at Dry-Processed RDF Facilities

Compounds potentially discharged to sanitary sewers with tipping and process floor washdown waters include pesticides and organic solvents draining from the solid waste while on the tipping floor. The magnitude of this problem is almost impossible to assess because of the infrequent and variable nature of both washing and of spills of organic materials. Most such undesirable compounds are to be isolated from solid waste streams; but occasionally illegal or inadvertent deposits may occur. No such occurrences were witnessed by or reported to the authors during the present investigation. The potential for adverse water-related problems occurring from this source is considered to be very small to negligible because of the extreme dilution provided by the sanitary sewage. The magnitude of this source of organic and inorganic materials would be essentially the same as in solid waste transfer stations used throughout the United States and many of these have drains for carrying washdown waters to sanitary sewerage systems. However, operators should be aware of the possible adverse consequences of flushing hazardous waste materials into sewer systems. If spills do occur, special means, other than washdown, should be used for cleanup.

Waters used for cooling bearings and sub-process units, such as for aluminum recovery, normally do not become contaminated with pollutants of concern and the low rates of use (50 to 100 gal/ton) preclude any adverse effects upon discharging them to a municipal sewerage system.

As with mass-burning facilities, the major water-related concern is with disposal of the bottom ash and fly ash residues remaining after burning of the refuse-derived fuel. The major constituents of concern are dissolved solids consisting primarily of chlorides, sulfates and heavy metals which can leach from the ash upon landfilling. When the burning operation is inefficient, organic materials remaining in the bottom ash may decompose in ash ponds as landfills and cause the leachate to have a high organic content.

Conventional methods of handling and disposing of boiler ash and fly ash from power plants receiving RDF include wet sluicing to ash holding ponds and landfilling of dry residues. Wastewaters produced upon ash sluicing present two modes by which pollutants may be transported to the environment: seepage into groundwater reservoirs beneath the ponds and overflow from ponds into surface streams.

The magnitude of these two problems was estimated in two ways using the Ames, Iowa, facility as a case example:

1. Leaching columns were used to determine the amounts of materials that could leach from ash deposits; and
2. Direct measurements were made of the quality of waters that come into short-term contact with ashes and eventually could become overflow and surface runoff.

Leaching Tests

Leaching tests were conducted by placing ash samples in glass columns. Distilled water was passed through these columns and the leachate was collected for periodic analysis. Batch tests using the EPA leaching procedure also were conducted. Complete descriptions of

the procedures used in conjunction with these leaching tests are given in Reference 15.

Analysis of the leaching data shows that peak concentrations exceeded maximum allowable concentrations to groundwater resources as proposed by EPA under authority of the Resource Conservation and Recovery Act [14] (Table 8). However, average concentrations in the column leachate and the metals concentrations as measured by the EPA test procedure were much lower than the peak concentrations and in all cases less than proposed allowable concentrations.

The amounts of water used per unit of ash in the leaching tests were much greater than would pass through the ash in a well-designed and well-operated landfill. Actual leachate concentrations, therefore, would be much greater and leachate volumes much less than in the leaching tests. Thus, it is likely that leachate control, such as collection and treatment or the use of liners, will be required if useable groundwater sources are located close to the landfill site.

Ash Pond Tests

Quality of ash pond overflow waters was assessed by collecting sluice waters directly from the sluice pipe discharge when the Ames power plant was burning at 100% load and when receiving a mixture of 80% coal and 20% RDF by Btu. These samples were coarse-filtered to remove large particles (see Reference 15 for details of sampling). The filtrate was then allowed to settle for 4 hours and the decant water was analyzed. This decant water was considered to represent the quality of water that would be considered for discharge or recycle. The ash removed by coarse filtering was used in the column leaching tests to

Table 8. Concentration of contaminants in leachate potentially produced upon land-filling of ash from power plants co-firing coal and refuse-derived fuel.

Constituent	Ames boiler ash leachate (coal + RDF) ^a			Ames boiler ash leachate (coal only) mg/l	Water quality standards		Constit- uents of Concern
	Concentrations, mg/l		Total leachable		Limits to groundwater (MCL) ^d mg/l	Toxic waste Threshold, ^c mg/l	
	Peak	Average	mg/g(S _d)				
CONVENTIONAL POLLUTANTS							
pH	9.9						
Chemical oxygen demand	<u>233</u>	19.5	0.78(0.54)	8-11	N ^d	N	*,?
Biochemical oxygen demand	<u>87</u>	3.7	0.15(0.09)	1.6-1.7	N	N	*,?
Suspended solids	--	--	--	--	N	N	
Total dissolved solids	<u>2579</u>	312	12.5(7.6)	533-593	<u>500</u> ^e	50,000 ^e	*,?
Volatile dissolved solids	508	68	2.7(0.44)	90-115	N	N	
Alkalinity	255	38	1.5(0.91)	19-75	N	N	
Calcium	--	--	--	--	N	N	
Magnesium	--	--	--	--	N	N	
Sodium	--	--	--	--	N	N	
Potassium	--	--	--	--	N	N	
Chloride	123	7.1	0.28(0.24)	38-44	250 ^e	25,000 ^e	
Sulfate	<u>1610</u>	124	5.0(3.69)	238-257	<u>250</u> ^e	25,000 ^e	*,?
Fluoride	0.39	0.46	0.02(0.008)	0.51-0.70	1.4-2.4	140-240	
Nitrite + nitrate	0.29	0.09	0.003(0.005)	0.07	10 ^e	100 ^e	
Total Kjeldal nitrogen	47.1	1.09	0.043(-)	0.89-0.93	N	N	
Ammonia nitrogen	5.1	0.46	0.018(0.010)	0.63-0.69	N	N	
Total phosphate	1.85	0.21	0.008(0.008)	0.14-0.31	N	N	
Iron	--	--	--	<u>7.5</u>	<u>0.3</u>	30 ^e	*
Manganese	--	--	--	0.31	0.05	5 ^e	*

Table 8. Continued.

Constituent	Ames boiler ash leachate (coal + RDF) ^a			Ames boiler ash leachate (coal only) mg/l	Water quality standards		Constit- uents of Concern
	Concentrations, mg/l		Total leachable mg/g(S _d)		Limits to groundwater (MCL) ^b mg/l	Toxic waste Threshold, ^c mg/l	
	Peak	Average					
HEAVY METALS							
Arsenic	--	7x10 ⁻⁵	1.3x10 ⁻⁶	0.007	0.05	5.0	
Barium	--	0	0	0.50	1.0	100	
Cadmium	2x10 ⁻³	9.2x10 ⁻⁵	3.7x10 ⁻⁵	<0.006	0.01	1.0	
Chromium	--	3.3x10 ⁻⁴	6.7x10 ⁻⁶	0.02	0.05	5.0	
Lead	<u>0.175</u>	0.037	1.5x10 ⁻³	<u>0.050</u>	<u>0.05</u>	5.0	*,?
Mercury	--	0	0	0.0005	0.002	0.2	
Selenium	--	0	0	<0.0007	0.01	1.0	
Silver	--	4.7x10 ⁻⁴	9.3x10 ⁻⁶	0.010	0.05	5.0	
Copper				0.093	5.0	500	
Zinc				1.66	1.0	100	

PESTICIDES

(No pesticides, PCB's or organic priority pollutants found present)

^aWhen burning 80 to 90% coal + 10 to 20% RDF by Btu content.^bBased on limits established or proposed by EPA under authority of RCRA or assumed equivalency to Safe Drinking Water Act standards.^cBased on limits for toxicity as established or proposed by EPA under authority of RCRA.^dN = no specific standards established.^eTentative or anticipated standard [14].

simulate the effect of allowing holding pond waters to seep into underground resources.

Additional tests involved long-term contact of bottom ash and fly ash with the sluice water. In this case, representative samples of the sluice water and ash solids were collected during a bottom ash sluice period and again when fly ash was being sluiced. These samples were allowed to set undisturbed until, periodically, they were agitated and a portion was withdrawn for analysis. These portions were centrifuged and filtered to remove solids and the filtrate was analyzed.

The analyses of sluice samples after short-term (24 hours) and long-term (39 days) contact are summarized in Table 9. Most analyses showed relatively close agreement between short-term and long-term contact, but some differences are noteworthy. The COD and BOD increased in the bottom ash samples upon long-term contact. No doubt, this was caused by hydrolysis or microbial decomposition of the unburned organic materials in the samples. The sulfate concentration decreased, in all probability because of conversion to sulfides by bacterial action in the anaerobic environment. Total dissolved solids increased upon long-term contact because of the greater time available to dissolve salts contained in the ash.

There was little difference in the conventional pollutant concentrations occurring when burning coal only and coal + RDF, indicating that the water pollution problems associated with burning RDF with coal are not measurably different from those when burning coal only. Similarly, heavy metals concentrations were not appreciably different when burning coal plus RDF as compared to when burning coal only (Table 9).

Table 9. Concentration of contaminants in overflow waters from ash sluice ponds when burning coal only and coal plus refuse-derived fuel.

Constituent	Ash pond overflow (coal + RDF), mg/l										Quality requirements		
	Ash pond overflow (coal-burn only), mg/l										Direct discharge ^a mg/l	Dis-charge to sewerage system ^b mg/l	Constit- uents of concern
	Short-term contact		Long-term contact		Short-term contact				Long-term contact				
	Bottom ash	Fly ash	Bottom ash	Fly ash	Mixed unsettled	Mixed settled	Bottom ash	Fly ash	Bottom ash	Fly ash			
CONVENTIONAL POLLUTANTS													
Chemical oxygen demand	8-11	4-9	11	6	--	--	33	2.9	201	6.8	>200 ^c	~300	
Biochemical oxygen demand	1.6-1.7	2.9-12	3	1.6	<1	<1	25	1.5	>47	0.83	10-30	~300	*
Suspended solids	--	--	--	--	242	80	--	--	31 ^d	4 ^d	10-30	~300	
Total dissolved solids	533-593	1,382-1,687	625	1,540	566	571	639	1,382	758	1,214	500 ^c	50,000 ^c	*
Volatile dissolved solids	90-115	108-129	49	100	257	253	92	113	198	249	N ^e	N	
Alkalinity	19-75	92-1,302	40	589	218	116	238	93	460	156	N	N	
Calcium	--	--	--	--	147	90	--	--	65 ^d	135 ^d	N	N	
Magnesium	--	--	--	--	36	33	--	--	20 ^d	40 ^d	N	N	
Sodium	--	--	--	--	26	25	--	--	256 ^d	29 ^d	N	N	
Potassium	--	--	--	--	66	6.7	--	--	68 ^d	8.8 ^d	N	N	
Chloride	38-44	26-29	42	24	38	39	44	37	72	49	<250 ^c	<25,000 ^c	
Sulfate	238-257	635	316	593	265	197	245	639	1.1	106	<250 ^c	<25,000 ^c	*
Fluoride	0.51-0.70	0.38-0.70	0.40	0.54	--	--	0.83	1.21	0.58	0.52	<1.4-2.4 ^c	<140-240 ^c	
Nitrite + nitrate	0.07	0.02-0.05	0.05	0.04	0.10	0.11	0.05	0.04	0.15	0.08	<10 ^c	<1,000 ^c	
Total Kjeldal nitrogen	0.89-0.93	0.88-1.27	0.72	0.95	1.8	1.2	0.69	0.18	1.48	0.93	N	N	
Ammonia nitrogen	0.63-0.69	0.70-0.78	0.58	0.87	0.83	0.73	0.25	0.68	0.27	0.60	2+	N	
Total phosphate	0.14-0.31	0.04-0.11	0.05	1.37	5.6	4.0	0.78	0.43	1.65	<0.26	N	N	

Table 9. Continued.

Constituent	Ash pond overflow (coal-burn only), mg/l				Ash pond overflow (coal + RDF, mg/l)						Quality requirements		
	Short-term contact		Long-term contact		Short-term contact				Long-term contact		Direct discharge ^a mg/l	Discharge to sewerage system ^b mg/l	Constituents of concern
	Bottom ash	Fly ash	Bottom ash	Fly ash	Mixed unsettled	Mixed settled	Bottom ash	Fly ash	Bottom ash	Fly ash			
CONVENTIONAL POLLUTANTS (continued)													
Iron	--	--	--	--	<u>7.5</u>	0.35	--	--	<u>22.4</u>	0.02	0.3 ^c	3 ^c	*
Manganese	--	--	--	--	<u>0.31</u>	0.04	--	--	<u>0.19</u>	0.02	0.05 ^c	0.5 ^c	*
HEAVY METALS													
Arsenic			0.07	<0.0005	0.014	0.008					0.05	<1	
Barium			0.50	0.70	0.70	0.50					1.0	<2.5	
Cadmium			<0.006	<0.006	0.005	0.02					0.01	<3	
Chromium			0.02	0.01	0.05	0.02					0.05	<8	
Lead			0.05	0.05	<u>0.33</u>	<0.06					<u>0.05</u>	<3	*
Mercury			0.0005	<0.0002	<0.0003	<0.0003					0.002	<0.1	
Selenium			<0.0007	<0.0007	0.0004	<0.0006					0.01	<1	
Silver			0.010	0.007	0.005	<0.005					0.05	<1	
Copper			0.093	0.020	0.46	0.068					1.0	<6	
Zinc			1.66	0.38	1.38	0.11					5.0	<8	
PESTICIDES (No pesticides, PCB's or organic priority pollutants found present)													

^aBased on stream discharge standards established under authority of the Clean Water Act or assumed equivalency to Safe Drinking Water Act standards.

^bBased on limits for toxicity established by EPA under authority of RCRA or typical industrial pretreatment standards.

^cTentative or anticipated standard [14].

^dThese measurements were made on a settled but unfiltered sample.

^eN = no specific standards established.

No organic priority pollutants, pesticides, or PCB's were found in any of the sluice water samples or in the solid residues.

The data in Table 9 show clearly that ash pond overflow produced at power plants receiving burning coal alone or coal plus RDF is of sufficiently poor quality that direct discharge to surface streams is not likely to meet surface water standards as established by EPA or most states. Treatment also will be needed, if direct discharge is practiced, to reduce the soluble salt and heavy metal content. Some method of reducing the concentration of organic materials such as biological treatment, will be required if unburned organic matter exists in the bottom ash deposited in the ash ponds. However, recent tests at Ames shows that boiler modifications can essentially eliminate the discharge of organic matter with the bottom ash [19].

Treatment Possibilities

Potential pollution problems with ash sluice water storage and disposal can be solved or reduced significantly in three ways:

1. Dry handling of the ash,
2. Lining or sealing of ash ponds and treatment of overflow waters, and
3. Recycle of ash pond overflow.

Dry handling is becoming more common especially with fly ash from electrostatic precipitators. This ash generally is placed in sanitary landfills along with boiler ash and is covered to reduce its movement and to minimize contact with water. This latter factor must be considered carefully because waters passing through buried ash residues can present possible groundwater contamination in much the same manner as water

leaching from ash ponds. Most landfills, however, are designed to minimize the passage of water and should be acceptable for disposal of ash from refuse-burning plants by the same means as used for disposal of ash from coal-fired power plants. A significant amount of fly ash presently is being used as a filler material for concrete and therefore has some market value. Bottom ash, however, has no widespread market value.

Ash pond overflow waters can be treated to meet discharge standards for most conventional pollutants. Biological treatment or addition of small amounts of activated carbon can be expected to reduce the BOD to below acceptable levels for direct discharge, but would add considerable expense to sluice water handling. However, removal of heavy metals and iron and manganese will require chemical treatment as used widely in metal processing industries. Treatment to reduce chlorides and total dissolved solids will be more difficult and would involve such processes as ion exchange and reverse osmosis or distillation. Such extreme treatment is considered to present unacceptable cost restrictions and the need for such treatment prior to discharge would be precluded by use of dry handling of ash or by complete recycle of sluicing waters.

Complete holding and recycle of ash sluice waters presents an alternative to discharge. Possible problems still exist, however, because as the number of reuses increases, the soluble salt content increases. This can cause significant corrosion of metal pipes, pumps and ash hoppers. Neutralization can help to reduce corrosiveness but may not eliminate the problem altogether. Corrosiveness also can be reduced by periodically wasting some of the water in inventory and

replacing it with fresh water, but these blowdown waters may then themselves present disposal problems because of their high salt content.

Unfortunately, no RDF-burning plants presently (1980) use sluice-water recirculation, so no baseline data are available from which to make an assessment of the corrosion problems. Complete recycle of boiler ash quench waters at the Saugus, Massachusetts, mass-burning plant reportedly has presented no corrosion problems; but in this case, a significant blowdown occurs because of the water carried out with the wet ash. Recirculation of ash pond overflow also is used at one of the Colorado Springs, Colorado, power plants, but only about 18 months of data are available, and this is too little time to show corrosion potential [12].

2.2.1.7. Water Use Management at Dry-Processed RDF Facilities

In most dry-processed RDF facilities, improved water use management, such as using spent bearing and process cooling waters for dust control and washdown, can reduce both water use and wastewater production significantly. If more water is used than is needed for dust control and washdown, selective discharge of the less polluted stream, for example, bearing and other cooling waters, to the sanitary sewer can eliminate the release of wastewaters that could cause adverse impact on municipal wastewater treatment systems.

2.2.1.8. Cost of Wastewater Treatment at Dry-Processed RDF Facilities

Accurate costs for a suitable means of handling wastewaters associated with ash disposal at RDF-burning power plants are difficult to obtain because of the lack of operating experience with treatment or recycle. Costs for the presently operating coal-burning facility at

Ames, Iowa, were used to project costs for a power plant designed to co-fire RDF with coal. These costs are listed in Table 10.

Assuming that these unit costs are doubled for each ton of RDF burned because of the higher ash and lower Btu content, the cost for ash sluicing and sluice water handling contributed by burning RDF would be about \$0.50 to \$1.26/T_{RDF} or about \$0.30 to \$0.75/ton of raw refuse assuming 60% goes to RDF.

Table 10. Estimated costs for water-related environmental controls at power plants co-firing coal and refuse-derived fuel.

Sluice water handling method at Ames	Costs ^a			
	\$/T _{coal} [19]	\$/MBtu	\$/T _{RDF}	\$/T _{sw}
Unlined pond with minimal dredging	0.25	0.01	0.50	0.30
Clay lined pond with no ash removal and with water recirculation	0.63	0.06	1.26	0.75
Landfilling ash residues	--	0.02 to 0.04	0.2 _b to 0.8 _b	0.12 to 0.48

^aBased on co-firing 80% coal and 20% RDF by Btu content.

^bBased on \$1 to \$4/T_{ash} and 20% ash content in RDF.

Therefore, settling and recirculation of ash sluice waters seems to be the most economical means of reducing wastewater discharge and related environmental impacts at power plants receiving dry-processed RDF.

2.2.2. Wet Pulping

Wet pulping of solid wastes involves placing the material into a large pulper somewhat analogous to a large household garbage grinder (Fig. 23). A thick slurry of mixed wastes is formed, and heavy particles of glass, ferrous metals, aluminum, etc., are separated by centrifugal action. The slurry containing the organic materials is dewatered by screening and pressing, and part or all of the liquid stream is recirculated to the pulper. The pulp can be cleaned and dried for use in paper products or can be dried or dewatered and burned for energy. Wet processing facilities in the United States are listed in Table 11.

Depending on the combination of energy recovery and materials separation systems, water is required for pulping, cleaning, bearing-cooling, and materials recovery. In most cases, the quality of water is not critical. This permits the use of wastewater treatment plant effluents, seawater, and other nonpotable supplies. The largest quantity of water is used in the pulping system. This water consists of recirculated process water from dewatering and materials recovery units plus make-up for losses with the wet pulp and other residues.

The Franklin, Ohio, plant has been the site of "proof-of-concept" testing as well as some air and water quality evaluations. Most of this work was conducted while operating in an "open-loop" (minimum recirculation) mode which involved large amounts of water use and wastewater production. Only limited tests have been conducted with systems operating in the "closed-loop" or maximum recirculation mode as is planned for the full-scale units at Hempstead, New York, and Dade

Fig. 23. Schematic diagram of a wet pulping solid waste processing/resource recovery plant. (Figure Courtesy Black-Clawson Fibreclaim, Inc., New York, N.Y.)

HYDRASPOSAL™/ FIBRECLAIM™
SOLID WASTE RECYCLING SYSTEM
 FRANKLIN, OHIO, FACILITY.
 By BLACK CLAWSON FIBRECLAIM, INC. NEW YORK, N.Y.

Table 11. Wet pulping facilities design for recovering energy from municipal solid wastes [8,9].

Location	Owner	Design Capacity	Start-up Date	Status
Franklin, Ohio	Black Clawson	25	1978	Operational from 1971 through mid-1979
Hempstead, New York	Hempstead Resource Recovery Corporation	2,000	1980	In shakedown
Dade County, Florida	Dade County	2,500	1981	Under construction

County, Florida. Developers of this process have stated that "there will be no liquid discharged from these newer facilities [22]." Occasionally, however, some blowdown of recirculated water may be required for controlling the buildup of soluble salts and organic materials. The Franklin, Ohio, tests indicated that it should be possible to discharge blowdown streams to sanitary sewers under controlled release without causing adverse effects on municipal wastewater treatment systems that have been designed to accept the increased load.

However, there is a need for characterizing blowdown waters because of the present lack of data to confirm this apparent compatibility with municipal wastewater. Unfortunately, because of the proprietary nature of the process and because no federal or state funds were used at the Hempstead, New York, or Dade County, Florida, plants, analysis of water streams has been rather limited and access to sites has been restricted.

Because of the lack of data, it is not possible to assess costs for treating blowdown wastewaters or wastewaters produced at power plants receiving RDF produced by wet pulping processes.

2.2.2.1. Franklin, Ohio

The Black Clawson HydrasposalTM/FiberclaimTM demonstration plant located at Franklin, Ohio, was in operation from June 1971 through June 1979. The Franklin plant has a design capacity of 150 TPD of solid waste, and consists of three major subsystems (Fig. 24): a pulping and separation subsystem consisting of wet pulping, magnetic and centrifugal separation, and glass and aluminum recovery; a dewatering and incineration subsystem which dewateres the organic rejects and burns them in a

Fig. 24. Solid waste flow diagram for the Black Clawson HYDRASPOSAL/FIBERCLAIM plant located at Franklin, Ohio.

fluidized-bed incinerator; and the FiberclaimTM subsystem which recovers fiber from the pulped material.

To avoid confusion in terminology, definitions of the following terms are presented:

Process water--refers to the final effluent from the Miami Conservancy District (MCD) regional wastewater treatment plant which was used in the wet pulping process for cleaning, cooling and elutriation.

Whitewater--a term used in the pulp and paper industry which, in this particular situation, refers to the liquid stream consisting of recirculated process water, water from dewatering operations, and water contained in the raw solid waste.

Process stream--refers to the continuing stream exiting one process unit and entering the next processing operation.

Reject stream--the stream containing the removed material which exits the processing unit.

Organic reject--the organic material that is not reclaimed as fiber.

Solid waste from collection vehicles is unloaded onto a partially enclosed tipping floor. A front-end loader pushes the refuse onto a conveyor which transports the refuse to the Hydrapulper. The refuse is mixed with whitewater and macerated by the rotor located at the bottom of the Hydrapulper (Fig. 25). Metals and other heavy materials are forced by centrifugal action into the junk remover which conveys the material to a magnetic separator where ferrous metal is recovered.

Fig. 25. Inside a Hydrapulper™.

Non-ferrous material can be recycled back to the Hydrapulper, landfilled or separated for reclaiming.

Pulped refuse leaves the Hydrapulper through a perforated plate located at the base of the Hydrapulper and is pumped to the liquid cyclone. A liquid cyclone separates the material into light and heavy fractions. The "heavies," consisting of glass, small pieces of metal, etc., are rejected at the base of the cyclone into a grit chamber where the material is dewatered and conveyed to the glass plant. The light fraction can either be transported to the FiberclaimTM subsystem or to the dewatering subsystem.

In the normal mode of operation of the fiber recovery system (FiberclaimTM), the light fraction from the liquid cyclone enters the system via the selectifier dilution tank, where the material is further diluted with whitewater (Fig. 26). The liquid stream is then directed to the selectifier screen where the material is separated according to size. The larger fraction is rejected to the dewatering subsystem and the smaller material is conveyed to the centrifugal cleaners. The centrifugal cleaners remove grit, glass, and other dense material which is directed to the dewatering subsystem. The process stream from the centrifugal cleaners is directed to the run-down screens for further separation. The liquid slurry reject stream from the run-down screen is conveyed to the dewatering subsystem and the process stream is directed to the barrel thickener (Hydradenser) and cone press. These units dewater the pulped material. The liquid reject streams enter the whitewater recirculation system. The dewatered fiber is processed for reuse.

Fig. 26. Schematic diagram showing points of water input and recirculation streams for the Black Clawson HYDRASPOSAL/FIBERCLAIM plant located at Franklin, Ohio.

When fiber is not reclaimed, the fiber recovery system can be operated in a thickening mode to produce a concentrated cake suitable for burning as a refuse-derived fuel. In this mode the process stream from the selectifier screen bypasses the centrifugal cleaners and enters the run-down screens (not shown on figures). The process and reject streams from the run-down screens are directed to the dewatering subsystem. The objective of this mode of operation is to increase the solids content of the liquid cyclone process stream.

The dewatering subsystem consists of barrel thickeners (Fig. 27) and a cone press (Fig. 28) to dewater the pulped material. The dewatered stream is then burned in a fluidized-bed incinerator which uses a venturi scrubber to control air pollutants.

The Franklin plant, which operated from 1972 through June 1979, is located adjacent to the new Miami Conservancy District (MCD) regional wastewater treatment plant. This closeness permitted combined use of the two plants. The wet processing plant used final effluent and waste sludge from the MCD wastewater treatment plant as process water, and in turn sent the wastewater produced in the wet-pulping operation to the MCD facility for treatment. In facilities where this arrangement is not possible, the wet processing plant can be operated on a closed-loop basis.

Wastewater Quality

During normal operation of the wet processing facility for fiber recovery, three water streams are used (Fig. 26). Process water is used for elutriation in the liquid cyclone and centrifugal cleaners, as cooling water for bearings and oil pumps, and as a cleansing spray in

Fig. 27. Black Clawson hydradensifier.

Fig. 28. Black Clawson cone press.

the run-down screens. Whitewater is used in the Hydrapulper and in the selectifier dilution tank.

Three wastewater streams were produced during normal operation of the Franklin wet processing plant (Fig. 29). The first stream was the ash slurry from the venturi scrubber. The second was the blowdown from the whitewater system to control the buildup of solids. The third stream was discharged from the sewage sump in the dewatering and incineration subsystem. This stream was segregated from the other process systems to avoid contamination from dewatering of sewage sludge.

A. M. Kinney, Inc. [23,24] studied the Franklin plant during its first twelve months of operation. At that time, all process water came from the city water supply and water use averaged 2,537 gal/T of refuse processed. During the study period, no sewage sludge from the MCD wastewater treatment plant was incinerated. Consequently, only two wastewater streams were produced. Table 12 summarizes the average condition of the two streams.

In 1974, Systems Technology Corporation (SYSTECH) of Xenia, Ohio, began a nine-month technical, economic, and environmental evaluation of the Franklin facility [25]. Water usage averaged 3,600 gal/T of refuse processed. Of this amount, 2,300 gal/T came from the final effluent of the MCD wastewater treatment plant. The remaining 760 gal/T came from the city water supply. Some 48,900 gal of whitewater per ton of refuse were recirculated to the hydrapulper. The whitewater circulated through the selectifier dilution tank averaged 1,580 gal/T of refuse.

During the SYSTECH study, the wet processing plant was operated on a closed-loop basis for a short time. In this mode of operation, the

FRANKLIN, OHIO

Fig. 29. Schematic diagram showing points of wastewater production and treatment for the Black Clawson HYDRASPOSAL/FIBERCLAIM plant located at Franklin, Ohio.

Table 12. Wastewater characteristics for the wet processing system [23,24].

Parameter	Whitewater blowdown	Ash slurry
Flow	300,000 gpd or 2,043 gal/ton of refuse	50,000 gpd
pH	5.6	8.9
5-day BOD	3,973 mg/l	--
Suspended solids	5,119 mg/l	12,438 mg/l
Total solids	--	14,715 mg/l
Dissolved solids	3,739 mg/l	2,732 mg/l
Settleable solids	5,675 mg/l	9,941 mg/l
Total volatile solids	--	1,483 mg/l

only output of water from the system was the vapor from the fluidized-bed incinerator. Under closed-loop conditions, the water usage averaged only 62 gal/T of refuse processed.

Sewage sludge from the MCD wastewater treatment plant was incinerated during the SYSTECH study. Consequently, three wastewater streams were produced. Table 13 summarizes the average conditions of the three wastewater streams.

Wastewater Treatment

The treatment system at the MCD wastewater treatment plant consists of separate primary clarification of municipal and industrial wastewater, combined activated sludge secondary treatment, and chlorination of the final effluent.

The ash slurry from the venturi scrubber contained primarily biologically-inert suspended and dissolved solids (Table 13). This stream was directed to the industrial waste primary clarifier at the MCD wastewater treatment plant. Very little organic loading to the secondary treatment plant was created by the discharge of the ash slurry. Unfortunately, no detailed analysis of the metals content of this ash slurry was permitted prior to shutdown of the plant.

Table 13. Wastewater characteristics for the wet pulping process when using open-system water flow [25].

Parameter	Thickener Wastewater	Whitewater Blowdown	Ash Slurry
Flow	0.042 MGD	0.11 MGD	0.01 MGD
5-day BOD	2660 mg/l	2840 mg/l	18.22 mg/l
COD	6798.9 mg/l	8954.3 mg/l	356.84 mg/l
Total solids	7214.54 mg/l	7195.91 mg/l	8430.46 mg/l
Dissolved solids	3224.45 mg/l	2822.9 mg/l	2826.46 mg/l
Suspended solids	2882 mg/l	4795 mg/l	5453.15 mg/l
pH	4.8	5.78	5.4
Ammonia nitrogen	27.4 mg/l	28.85 mg/l	3.03 mg/l

The sewage sump discharge and the whitewater blowdown could be considered equivalent to concentrated industrial waste streams (Tables 13 and 14). These two streams were discharged to the municipal waste primary clarifier at the MCD wastewater treatment plant. At a combined

Table 14. Average concentrations of total metals in the whitewater blowdown [25].

Metal	Average concentration
Cadmium	92.5 µg/l
Manganese	495.0 µg/l
Zinc	557.0 µg/l
Nickel	3,990.0 µg/l
Iron	3,990.0 µg/l
Lead	6,225.0 µg/l
Tin	190.0 µg/l
Chromium	700.0 µg/l
Copper	11.4 µg/l

average flow of 152,000 gpd, the two waste streams contributed an average BOD₅ loading of 3,665 lb/day of BOD₅. This represents a population equivalent of 21,600 people, which was roughly equal to the number of persons served by the wet-pulping facility. Nutrient concentrations (nitrogen and phosphorus) were similar to concentrations found in domestic sewage. The two waste streams also contained moderate amounts of heavy metals (Table 14), but there was sufficient dilution from municipal sewage to eliminate any problems of toxicity in the secondary treatment process. Consequently, the discharge of wastewater from the wet processing plant to the MCD wastewater treatment plant did not create any major problems with the operation of the treatment plant. In a situation where the whitewater blowdown and sewage sump discharge

constitute the major flows to a small wastewater treatment plant, the heavy metal concentrations could present a problem.

2.2.2.2. Cost of Wastewater Treatment at Wet-Pulping Facilities

The cost of wastewater treatment at wet-pulping facilities will depend to a great extent on whether the system is designed for open-loop or closed-loop operation. Developers of the pulping process (Black Clawson, New York) have stated that full-scale pulping systems such as that at Hempstead, New York and Dade County, Florida, will be designed for closed-loop operation and that "there will be no wastewater discharge" [22].

However, should wastewater discharge be required as blowdown to control process water salinity, the concentrations of organic constituents and salts almost certainly will be considerably greater than shown in Tables 12, 13 and 14 where open-loop operation was used. The Franklin, Ohio, experience suggests that if the rate of release of these blowdown waters is controlled, there will be no adverse effects on municipal wastewater treatment plants if these plants are designed to accept the increased load.

It is quite likely that wastewaters discharged from wet-pulping processes will be subject to local, state and federal pretreatment requirements, thereby requiring some type of pretreatment prior to discharge to municipal sewerage systems. Unfortunately, because of the proprietary nature of the process and the fact that no federal funds were used in the Hempstead, New York, and Dade County, Florida, plants, the investigators were not permitted to collect samples for analysis and evaluation of treatment requirements. Therefore, no accurate assessment of costs can be made.

2.3. PYROLYSIS PROCESSES

2.3.1. General Description

Pyrolysis involves heating refuse to a sufficiently high temperature in an oxygen-deficient environment so that the organic materials break down chemically. The heat for pyrolysis of municipal refuse usually is obtained by burning part of the refuse. The products of the pyrolysis reaction can be broken into three component streams: (1) a gas consisting primarily of hydrogen, methane, carbon monoxide, and carbon dioxide; (2) an oily or liquid fraction that contains organic chemicals such as acetic acid, acetone and methanol, plus water derived from hydrolysis of organic compounds; and (3) a solid char fraction consisting of unburned carbon plus inert materials such as glass. Various systems are operated under different conditions to regulate the relative amount of gas, oil, and char products.

The major pyrolysis processes under development in the United States are listed in Table 15. A schematic diagram of one type of pyrolysis facility, showing individual processing steps, is given in Fig. 30.

Water is used at pyrolysis plants for cooling, gas scrubbing, char quenching and miscellaneous housekeeping. Wastewater streams of major concern are those collected from scrubbers, condensers or other gas cleaning devices. These wastewaters usually are high-strength and contain a variety of materials formed either by pyrolytic reaction or by vaporization from the raw solid waste.

Table 15. Large-scale pyrolysis systems in the U.S. [8,9].

Location	Key participants	Process	Design capacity	Products	Start-up date	Status
Baltimore, Maryland	Monsanto Environ-Chem Systems, Inc; City of Baltimore; EPA	Landgard TM Process: shredding, water quenching, magnetic separation	1,000	Steam, ferrous, glassy aggregate	1975	Monsanto Environ-Chem Systems, Inc has withdrawn from the project; revised by City of Baltimore, operational 1980
El Cajon, California	Occidental Petroleum Corp; San Diego Co; EPA	Flash Pyrolysis TM process: shredding air classification, magnetic, and other mechanical separation, froth flotation	200	Pyrolytic oil, ferrous aluminum, glass cullet	--	Plant is currently not operating pending possible modification to correct problems in pyrolysis unit
Erie County, New York	Carborundum Torrax, Inc; Erie County; EPA	Slagging pyrolysis system	75	Pyrolysis gas/steam	1974	Demonstration plant closed. Three systems sold in Europe
S. Charleston, W. Virginia	Linde Division, Union Carbide Corp.	Purox TM oxygen converter, shredding	200	Pyrolysis gas	1975	Operational until 1979
Redwood City, California	Pyro-Sol, Inc	Indirect heat; cooling process	50-75/module	Gas, high-carbon char	no	In development stage

Fig. 30. Schematic diagram of a pyrolysis plant (Union Carbide PUROX™) [26].

Wastewaters produced at pyrolysis processes usually are high-strength and contain a variety of organic materials formed during the pyrolytic reaction or vaporized from the raw wastes. Many of these materials are condensed in wet scrubbers and are water soluble. Only wastewaters from Union Carbide's PUROXTM process were available for analysis during the present investigation.

2.3.1.1. Baltimore, Maryland

The design of the solid waste-to-energy system in Baltimore, Maryland, was based on the LandgardTM process developed by Monsanto Chemical Co. This system was designed to process 1000 TPD of solid waste; but soon after start-up, the plant was plagued with mechanical problems. The City of Baltimore has since made extensive modifications and the plant now operates at a reduced rate of about 600 TPD.

Refuse collection vehicles unload solid waste in a receiving building (Fig. 31). Two bulldozers push the solid waste onto separate conveyors, each leading to two shredders operating in parallel. The milled refuse is conveyed to a transfer tower which directs the waste to either an Atlas storage bin (Fig. 32) or directly to a rotary kiln. Refuse is fed into a rotary kiln by twin hydraulic rams. Figure 33 shows the flow of solid waste through the plant.

The kiln is refractory lined and has a design throughput of 42 tons of milled refuse per hour (Fig. 34). The solid waste is partially burned using about 40% of the theoretical air requirements. The pyrolytic gas moves in a direction counter to the flow of refuse in the kiln and exits at the feed end. Number 2 heating oil, when needed as a supplemental fuel, is used at the discharge or firing end of the kiln.

Fig. 31. Baltimore receiving building.

Fig. 32. Atlas storage bin.

Fig. 33. Solid waste flow diagram for the pyrolysis plant at Baltimore, Maryland.

Fig. 34. Rotary kiln of landgard system.

Fig. 35. Air injection port of afterburner.

The gas produced cannot be compressed and transported to another location for combustion and must be burned on site (Fig. 35).

A wet-scrubber was used in the original design for air pollution control (Fig. 36). The scrubber was designed to serve three purposes: to cool the exhaust gases from the waste heat boilers, causing some of the vaporized organic and inorganic materials to condense or precipitate; to remove particulates from the gases; and to neutralize acidic gases. A dehumidifier was installed to receive the scrubber discharge and remove moisture so that a visible plume would not occur (Fig. 37). Unfortunately the scrubber did not function as planned. Its efficiency of particulate removal was too low, and greater amounts of water use were required than originally intended. The flue gases also were so acidic that the scrubber waters became very corrosive, thereby causing extensive damage to metal parts that were contacted by the recirculated scrubber waters.

Because of these problems, both the scrubber and dehumidifier were removed at the time of the 1978 plant revisions and replaced with dry electrostatic precipitators.

Char exiting the kiln drops into a water-filled quench tank (Fig. 38). Originally, this quenched material was conveyed to a materials recovery building where the solids were separated by flotation and metals were removed by magnetic separators (Fig. 39). However, this operation did not prove to be economical and has been terminated. Presently, all quenched char is landfilled.

Fig. 36. Baltimore scrubbing tower.

Fig. 37. Exhaust gas dehumidifier.

Fig. 38. Quench tank and residue conveyor.

Fig. 39. Direct transport of kiln residue to landfills.

Water Use

A closed-loop water system utilizing a cooling tower is used to cool the ram feeder and bearings of the rotary kiln (Fig. 40). Makeup water occasionally is added to the system to offset losses from evaporation and blowdown. City water is treated at the plant for use as a boiler feed water. This treatment includes ion exchange softening, degasification, neutralization and the addition of sodium sulfite and chelating agents. Water also is used to cool bearings in the shredders and other mechanical equipment. This water is used once and discharged to the sanitary sewer system via surface drains. Fire control systems are located in the receiving building, transfer towers, and the Atlas storage bins.

Water also is used for quenching the kiln residue or char. Water consumption is required to make up for losses from the char quench tank as wet residue is removed.

Data collected by SYSTECH [26] in 1977--when the scrubber was in operation--indicated that total water use, exclusive of cooling tower makeup, ranged from about 500 to 1500 gal/T of solid waste processed. Present total water consumption averages about 100 gallons per ton but no measurements have been made to show the quantity of water consumed at each point of use.

Wastewater Production

Water from wet refuse in the receiving building drains into a sump located beneath the refuse conveyor (Fig. 41). This wastewater is discharged to the sanitary sewer system. Sumps are also located beneath the floors of the transfer tower and Atlas storage building.

Fig. 40. Schematic diagram showing points of water use at the Baltimore, Maryland pyrolysis plant.

Fig. 41. Schematic diagram showing points of wastewater production within the pyrolysis plant at Baltimore, Maryland.

These sumps catch excess water from the sprinkler systems and discharge the water to the sanitary sewer system.

Bearing-cooling water from the two shredders is discharged to the sanitary sewer system. The flow rate from each shredder has been estimated to be about 10,000 gpd [26]. Cooling water from an air compressor and a turbine also is discharged to the sanitary sewer system. The closed-loop cooling system requires occasional blowdown. The quantity and frequency of the blowdown, which goes to the sanitary sewer system, depends on the characteristics of the water in the cooling system. When the scrubber was in operation, occasional blowdown was required to control the chloride levels in the system. This stream was directed to the sanitary sewer system. The new electrostatic precipitators require no water use and produce no wastewater. Boiler water blowdown constitutes the largest portion of the wastewater stream going to the sanitary sewer system. The blowdown is continuous with occasional blowdown of the mud drums.

Wastewater from the slag quenching and washing operation at the char conveyor is drained onto the ground and eventually into open drains to the sanitary sewer system.

The various wastewater streams are combined in the sewer lines at the plant. Consequently, there is only one total wastewater stream leaving the plant.

A major adverse water-related impact at this plant was associated with the scrubber system used for air pollution control. These waters were highly acidic and created a series of corrosion problems. Parts of the dehumidifier system were essentially destroyed by corrosion

(Fig. 42). Capture of chloride and sulfur compounds caused pH values to be as low as 3 to 4. Neutralization was used but that increased the salt content of the recirculated water, thereby increasing the amount of water which had to be wasted as blowdown.

The surface drains collecting quench waters and some bearing-cooling waters will permit some entrance of storm waters carrying with them solid residues deposited near the plant. The major impact of this storm runoff is to increase the volume of water added to the sanitary sewer system.

The hauling of wet quench tank residue presents a hazard and a nuisance on streets. This residue could be stockpiled on-site and permitted to drain prior to trucking to a landfill, but the drainage waters would require collection and discharge, most likely to the sanitary sewer system.

The major concern for wastewater quality and the need for treatment is associated with the char and slag quenching operations. Those wastewaters contain high concentrations of suspended solids, dissolved salts and soluble organic compounds. At the time of this writing, no detailed analysis of the treatability of this wastewater has been made.

2.3.1.2. South Charleston, West Virginia

The Union Carbide PUROXTM demonstration plant located in South Charleston, West Virginia, was operated periodically from 1974 through 1978. The plant capacity was rated at 200 TPD. The system uses pyrolysis to produce a medium Btu fuel gas. Pure oxygen is used to burn part of the waste and produce heat to pyrolyze the remaining organic solids.

Refuse from Charleston and from adjoining cities in West Virginia is delivered by truck to the receiving building (Fig. 43). A front-end

Fig. 42. Corrosion of effluent line from dehumidifier at Baltimore, Maryland.

Fig. 43. Solid waste flow diagram for the Union Carbide PUROX™ demonstration plant located at S. Charleston, West Virginia.

loader pushes the refuse onto a conveyor that transports it to the shredder. The shredded material then passes under a magnetic separator where 90% or more of the ferrous material is removed. The nonferrous portion is transported to the feed system near the top of the converter. Oxygen from a cryogenic oxygen system is injected into the refuse converter at its base. The shredded refuse descends by gravity through the vertical reactor where, at the bottom, the oxygen burns organic materials to create a temperature zone in the range of 3000 °F in the lower portion of the furnace. Heat rising from the bottom of the furnace pyrolyzes the incoming and downward moving shredded refuse. This action cools the gases and reduces their temperature to approximately 250° to 400 °F. Inorganic materials are transformed into a molten slag by the high temperatures. The slag drops into a water-filled quench tank via a slag duct. This material is then hauled to a landfill for final disposal.

Gases leaving the converter are directed to the scrubbing tower to help remove carbon particulates carried out of the converter. The scrubber exit gas stream is passed through a wet electrostatic precipitator and a small amount of condensed water is drawn off with an oily residue. The gas stream exiting the electrostatic precipitator is directed to the product gas condenser which cools the gas to about 100 °F or less. The bulk of the water vapor is removed in this unit. This condensate contains most of the organic materials which must be processed as wastewater. The product gas has an average heating value of 300 Btu per cubic foot.

Water Use

A closed-loop cooling system, including a cooling tower, is used to cool the refuse converter, the spray water cooler, and the product gas condenser. Occasional blowdown is required to control the solids level in the cooling water, thereby requiring that makeup water be added.

Water is used to quench the slag from the refuse converter (Fig. 44). Water lost by evaporation and that removed with the waste slag is made up by fresh water but could be obtained from a wastewater stream such as cooling tower blowdown.

About one gallon of clean water per ton of refuse processed per day is used in the scrubber tower to help clean the gas stream [27]. This water input, along with the water produced by pyrolysis of organic material and that brought in with the solid waste, causes the scrubber exit gas to become saturated. The scrubber water stream is recirculated through a vacuum filter to remove carbon carried into the gas stream from the converter. The carbon is then directed back to the refuse converter and the filtrate water is recirculated for reuse in the scrubber.

Wastewater Production

Water remaining in the gas stream exiting the scrubber is removed in the product gas condenser and combined with the water from the scrubber and then is passed through a vacuum filter to remove carbon char (Fig. 45). This water is recycled to the scrubber with any excess going to wastewater treatment. The volume of wastewater discharged at this point is about 80-100 gal/T of solid waste processed [27].

Fig. 44. Schematic diagram showing parts of water use in Union Carbide's PUROXTM plant located at S. Charleston, W. Virginia.

Fig. 45. Schematic diagram showing recirculated water stream and points of wastewater production at Union Carbide's PUROX™ demonstration plant located at S. Charleston, West Virginia.

Additional sources of wastewater include blowdown from the slag quench water system and the closed-loop cooling system. These discharges vary in quantity and frequency depending on water conditions in the respective systems.

2.3.1.3. El Cajon, California

The pyrolysis plant located at El Cajon, California, is a joint effort of the Occidental Research Corporation, the County of San Diego, and the U.S. Environmental Protection Agency. The demonstration plant was designed to process approximately 200 TPD of solid waste. Solid wastes are collected from the community of El Cajon, trucked to the plant in packer trucks and dumped onto a tipping floor (Fig. 46). A small front-end loader pushes the solid waste onto a conveyor that carries the material into a 1000 HP hammermill where it is ground to a nominal 3-in. size. The milled refuse is then conveyed to a magnetic separator where ferrous material is recovered.

The nonferrous fraction is then discharged onto a second flat floor from an overhead moveable conveyor belt (Fig. 47). This floor serves as an intermediate storage facility and can store several days' operating volume. A front-end loader pushes this material onto a conveyor that transfers the materials to a doffing roll bin from which the milled refuse is metered to an air classifier (Fig. 48). The air classifier separates the refuse into light and heavy fractions (Fig. 49).

The heavy fraction is passed through a trommel screen. From this, the fine material is transferred to a glass recovery process, the large fraction is conveyed back to the tipping floor, and the intermediate

Fig. 47. Overhead conveyor and storage floor.

Fig. 48. Doffing roll surge bin.

Fig. 49. Occidental air classifier.

Fig. 50. Froth flotation units for glass recovery.

size is passed to an aluminum separation system consisting of two-stage induction separators. The nonaluminum fraction is wasted, used as fill, or sold as scrap.

The light fraction from the air classifier is conveyed first to a dryer and next to a primary vibrating screen to remove grit, glass, and other heavy inorganics. The reject stream from the primary vibrating screen is passed through an air table where light organic materials are removed via density separation. The heavy inorganic stream from the air table is then combined with the fine fraction from the trommel screen. The combined material is separated by size in a second, smaller vibrating screen with the larger particles transferred to a rod mill for size reduction and then returned to the small vibrating screen. Fine diameter material from this vibrating screen is transferred to a two-stage air flotation process where glass and organic material are separated (Fig. 50). An industrial surfactant is added to enhance attachment of gas bubbles to the glass particles. The glass fraction is dewatered via a vacuum filter and sold to glass products manufacturers and other market outlets.

Organic material from the primary vibrating screen is passed through secondary grinders that reduce the material to a "fluff," similar in appearance to raw wool. The fluff is placed in a second doffing roll bin from which it is metered into the pyrolysis column.

The "Oxy" design is based on a fluidized-bed contact or flash pyrolysis process using ash as a contact and heat transfer medium. Organic solids (fluff) are mixed with this ash in a heat-pressure cycle, causing the organic material to pyrolyze and break down into

ash, an organic char, and volatile products. These products are separated in a cyclone separator and the volatile materials are passed to a condenser. Ash and char are passed through a char burner which burns the char to produce heat for operating the process and to produce more ash. Excess ash is drawn off at this point and the remainder is retained in the fluidized bed for process operation.

The Pyro FuelTM product is recovered from the high-temperature volatile stream by using No. 6 fuel oil in a venturi scrubber as a quenching material to cool the gas and to condense the previously volatile organic compounds. This mixture of condensed pyrolysis products, quench-oil, and remaining gases is placed into a phase-separation process. Here the heavy pyrolytic oil (Pyro FuelTM) settles to the bottom of a decant tank and is drawn off, stored, and sold. The quench oil floats on the pyrolytic oil and is decanted and reused for quenching. Presently, San Diego Gas and Electric Company is planning to use this material as a fuel supplement in their oil-fired San Diego power plant.

The remaining gas stream now contains only light volatile organic and inorganic gases. This stream is passed through a gas scrubber where water is used in a venturi scrubber to remove acidic materials. The remaining gas stream essentially contains only volatile organic materials and serves as a fuel source for the after-burner where obnoxious fumes from the char-burning process are burned to eliminate odors. Heat produced by the after-burner is recovered by heat exchangers and used in the dryer and the char burner. Exhaust gases from the after-burner are cleaned by bag-house filters before final emission to the atmosphere.

This pilot plant was constructed in 1976 and 1977 and, while the front-end process has worked well, the pyrolysis system has never been operated successfully. The major problem was one of inability to separate the char and ash from the gas stream so that it would be excluded from the gaseous vapor stream and made available for recirculation to the pyrolyzer. Extensive modification of the pyrolysis unit is considered necessary in order to make the system function properly. At the date of this report, plans for modification were still uncertain.

Water Use and Wastewater Production

Water is used for fire control in the receiving building and primary shredder and is used to control dust emissions around the shredder (Fig. 51). A closed-loop cooling tower system is used to cool the quench oil and scrubber water (Fig. 52). Occasionally makeup water is added to the system to account for losses due to evaporation and blowdown.

The glass recovery process represents perhaps the largest point of water use. Water is used to clean and separate the glass from the remaining heavy fraction. The water discharged from the glass plant is pumped to a clarifier where solids are removed (Fig. 53). The clarifier overflow is recycled back to the glass recovery plant. Solids are removed from the clarifier and dewatered via a vacuum filter. The liquid from the vacuum filter is discharged to the wastewater storage pit (Figs. 54 and 55). City water is added to the glass recovery process when needed.

During start-up of the plant, water is added to the gas scrubber system. After the plant is operational, the water used in the gas

Fig. 51. Schematic diagram showing points of water use at Occidental Petroleum's pyrolysis plant located at El Cajon, California.

Fig. 52. Cooling tower and scrubbing tower.

Fig. 53. Occidental glass recovery plant.

Fig. 54. Wastewater in storage pit.

Fig. 55. Wastewater storage pit.

scrubber is obtained from the breakdown of organic materials in the pyrolysis reactor. More water is produced than needed, with the excess being sent to wastewater storage or treatment (Fig. 56).

By design, and when operating properly, the Occidental Research Corporation pyrolysis process is "clean" relative to water use and wastewater production. Water use is kept to a minimum and the reuse of water produced from the pyrolysis reaction as scrubber water helps reduce water input requirements. The major organic load seems to come from the glass washing operation, where organic solids washed from the glass are dissolved and discharged with the vacuum filter underflow to the wastewater holding pond.

Studies were initiated by Occidental Research Corporation and by the U.S. EPA to determine the quantity and quality of the wastewater streams [28]. Because of the inability to operate the system as designed, no wastewater samples other than from the glass-recovery unit were collected.

2.3.2. Wastewater Quality and Treatment of Pyrolysis Wastewater

Because of the small number of pyrolysis processes constructed to date in the United States and because of the erratic schedule of those in operation, wastewater samples were available only from Union Carbide's PUROXTM facility at South Charleston, West Virginia. Thus the analysis of wastewater quality and treatment requirements presented in this report can be considered to apply only to that process. However, the types of compounds present in the PUROXTM process wastewater probably

are characteristic of pyrolysis wastewaters in general, and this should be taken into consideration when analyzing wastewaters from or designing treatment facilities for other pyrolysis processes.

Wastewater produced in the PUROXTM system has an extremely high organic content (Table 16). The daily organic load in the wastewater from a 200 TPD PUROXTM facility is equivalent to the domestic wastewater load from a population of about 45,000 people. This wastewater obviously requires treatment before it can be discharged to the environment.

Union Carbide Corporation performed biological treatability studies to determine the biodegradability of the PUROXTM system wastewater [29]. Their tests have shown that no inhibition of the biodegradability of the wastewater was detected after using a 19:1 dilution of the PUROXTM wastewater with municipal sewage. A major water use not included in the 80 to 120 gal/T amount cited previously is that required for diluting the pyrolysis wastewater stream so that it can be treated in a biological process. Almost any water can be used for this purpose and Union Carbide Corporation proposes using raw sewage.

Additional tests were conducted by the authors to determine further the ability to treat the wastewaters from the PUROXTM process using both conventional and advanced physical/chemical processes. The treatment processes evaluated consisted of:

1. Biological treatment by both anaerobic and aerobic processes,
2. Chemical coagulation using lime and alum, and
3. Activated carbon adsorption.

These processes were selected because they have been used successfully to treat similar types of wastewaters. Other possible treatments such

Table 16. Characteristics of untreated PUROXTM pyrolysis wastewater.

Parameter	Union Carbide [29]	Analytical Services Laboratory, ISU [31]
Flow, gal/ton of refuse	80-100	--
Temperature, °F	90-110	--
pH	3.45-4.5	2.2-4.2
COD	50,000-77,000 mg/l	41,718 mg/l
BOD ₅	30,000-52,000 mg/l	16,375 mg/l
TOC	--	12,625 mg/l
Total solids	--	18,680 mg/l
Suspended solids	--	2,115 mg/l
Volatile suspended solids	--	2,000 mg/l
Oil and grease, mg/l	500-1,000	--
Organics, weight %	--	--
Methanol	0.6-1.1	0.015
Ethanol	0.3-0.5	0.0035
Acetone	0.3-0.5	0.0015
Methyl ethyl ketone	0.06-0.1	0.0002
Acetic acid	0.5-0.8	0.522
Propionic acid	0.25-0.4	0.0575
Butyric acid	0.06-0.1	0.0635
Furfural	0.3-0.5	0.0065
Phenol	0.06-0.1	0.02
Benzene	0.03-0.06	0.0035
Other	0.2-0.38	--
Total	2.66-4.54	--

Table 16 (continued).

Parameter	Union Carbide [29]	Analytical Services Laboratory, ISU [31]
Ag	--	0.01 mg/l
As	--	0.132 mg/l
Ba	--	5.1 mg/l
Ca	--	440 mg/l
Cd	--	<0.05 mg/l
Cr	--	0.15 mg/l
Cu	--	0.02 mg/l
Cl	--	1,079 mg/l
Fe	--	59.2 mg/l
Hg	--	0.003 mg/l
K	--	185 mg/l
Mg	--	46.0 mg/l
Mn	--	62.8 mg/l
Na	--	445 mg/l
Ni	--	<0.01 mg/l
Kjel-N	--	1,200 mg/l
NH ₃ -N	--	7.39 mg/l
NO ₂ + NO ₃ - N	--	0.39 mg/l
Pb	--	1.25 mg/l
PO ₄ as phosphate	--	94.0 mg/l
Se	--	0.888 mg/l
SO ₄ as sulfate	--	520 mg/l
Zn	--	65.8 mg/l

as membrane processes (reverse osmosis, electrodialysis, etc.) and oxidation with ozone could possibly be used but have a number of disadvantages and typically are much higher in cost than are the chosen alternatives.

In the course of the pyrolysis reaction, very high temperatures are used to reduce organic matter, and the possibility exists that the chemical environment within the reactor is suitable for the formation of aromatics, polyaromatics and their substitute derivatives, many of which are organic priority pollutants [31]. Thus, it was desirable, while monitoring treatability of the wastewater from pyrolysis processes, to monitor the presence and fate of organic priority pollutants as well as the traditional parameters of treatment.

2.3.2.1. Wastewater Characteristics

Although wastewater is produced at a relatively low rate in a PUROXTM pyrolysis facility, the high organic loading makes its treatment an important objective in plant operation. Table 16 shows the composition of the PUROXTM pyrolysis wastewater as analyzed by Union Carbide and by the authors. The Union Carbide data represent averages of a number of samples collected during the period of operation, while the project analyses represent the quality of the sample obtained for use in the treatability tests conducted in this project.

The wastewater is an opaque fluid with a penetrating smoke odor that is noticeable even at low concentrations. The organic content is high as indicated by the high chemical oxygen demand (COD) and total solids concentrations. A significant part of the organics consist of short chain acids, alcohols and ketones. The low ratio of biochemical

oxygen demand (BOD) to chemical oxygen demand may suggest the presence of toxins but more likely occurs because much of the organic material is not biologically degradable.

An indication of the magnitude of the treatment requirements of this wastewater can be achieved by comparing its characteristics to those of domestic sewage. The BOD of the wastewater is about 30,000 to 50,000 mg/l and the flow is about 80-100 gallons per ton of solid waste processed. Thus, for a 200 ton per day processing plant the total load of the wastewater leaving the plant ranges from about 4,000 to 8,340 lb of BOD per day. If a BOD contribution of 0.18 lb per person per day is assumed, the population equivalency of the PUROXTM pyrolysis wastewater is about 22,000 to 46,000 persons. A 200 ton per day PUROXTM facility can serve a community of about 100,000 persons (assuming 4 lb of solid waste per person per day). Therefore, a 22 to 46% increase in organic loading could be expected at a sewage treatment plant serving a community with a PUROXTM pyrolysis facility if the wastewater from this facility is discharged to a municipal sewerage system. However, the volume of wastewater contributed by the pyrolysis facility would represent only about 0.2% of the total hydraulic load.

Analysis of the organic composition of the wastewater was made using the gas chromatographic/mass spectroscopy (GC/MS) method [32]. A total of 42 compounds having a definite peak response (peak area larger than 5% of the area of 20 mg/l d-10 anthracene) were found in extracts using methylene chloride at pH 11 (base-neutral compounds). Another 39 compounds were detected upon extraction with methylene chloride at pH 2. Of this total of 81 compounds, only six were identified definitely

as being organic priority pollutants as defined by the U.S. EPA (Table 17).

The acid-extractable compounds were fairly soluble and occurred to a large extent in the liquid fraction of the raw pyrolysis wastewater. Base-neutral extractable compounds predominantly were adsorbed to a greater extent on to the suspended solids in the sample. It is quite likely that the bis-(2-ethylhexyl)phthalate originated from plastic containers used for storage and treatment of this wastewater. Although the concentrations of these compounds were quite high when expressed as mg/kg (parts per million) of solids, the actual contribution of these adsorbed organics to the total volumetric concentration in mg/l was quite small.

2.3.2.2. Biological Treatment

Biological treatment of the PUROXTM wastewater was conducted using a laboratory-scale system as shown schematically in Fig. 57. This system consisted of four plexiglass column reactors, 5.5 inches in diameter and 4 feet in height. Wastewater mixtures were fed from individual feed bottles to each of the reactors using a peristaltic pump. The waste was thus fed uniformly throughout each day. Solids were wasted from the reactors once each day in amounts sufficient to achieve the desired solids retention time (SRT).*

The test program involved feeding a synthetic wastewater to one reactor that served as a control. The other three reactors also received

* Solids retention time is the average time that biological solids are retained in the reactor as determined by the ratio of the mass of solids held in inventory to the rate of solids removed each day for wasting. SRT is a major design parameter for biological treatment systems.

Table 17. Priority pollutants isolated from raw PUROXTM pyrolysis wastewater and their removal in biological treatment units operating at 10-day SRT and when receiving 5.6% pyrolysis wastewater by volume.

Organic compound		Untreated pyrolysis wastewater mg/l	Concentration by dilution mg/l	Treated effluent	
				Concentration, mg/l	Average percent reduction
O-chlorophenol	L	57	0.319	0.03	90.6
	S	--			
Phenol	L	300	16.8	0	100
	S	0.67			
Naphthalene	L	4.8	0.26	0.79	--
	S	0.31			
Acenaphthylene	L	2.6	0.17	1.04	--
	S	0.48			
Fluoranthene	L	0.3	0.06	0	100
	S	0.8			
Number of other acid extractable		37	--	8	97.1
Number of other base-neutral extractable		39	--	11	98.0
^a Liquid fraction only

Fig. 57. Schematic diagram of the laboratory-scale units used for biological treatment of pyrolysis wastewater.

synthetic wastewater but with varying amounts of the BOD replaced with unaltered pyrolysis wastewater as shown in Table 18. The purpose of using the synthetic wastewater was to simulate the organic load of a domestic wastewater to which the pyrolysis wastewater might be added.

The performance of the bench-scale treatment units indicated that there was a definite inhibitory effect caused by the pyrolysis wastewater when fed at high concentrations. Evidence of this toxicity is seen in the lower level of biological solids (measured as volatile suspended solids) occurring in the reactors receiving the higher percentages of pyrolysis wastewater (Fig. 58). The relative inhibitive effect was about the same at each SRT when feeding the same ratio of pyrolysis wastewater to synthetic wastewater. For example, the solids level in the reactors receiving 5.26% pyrolysis wastewater (PWW) by BOD contained from 45 to 55% of the volatile solids in the control reactor at all tests SRT's.

Comparison of effluent soluble organic material also supports this conclusion that toxicity occurred. The units operating at the lower SRT's contained more soluble chemical oxygen demand (COD) relative to the control unit than did those units operating at the higher SRT's (Fig. 59). Much of this increase in soluble COD may be attributable to the large fraction of nondegradable soluble COD in the raw pyrolysis wastewater. However, since equal organic loadings were used in all reactors receiving a given percentage of pyrolysis wastewater BOD, the increases in nondegradable soluble effluent COD should have been equal from one operating SRT to the other. This obviously did not occur, suggesting that the organisms could not adapt to the pyrolysis wastewater constituents at the lower SRT.

Table 18. Composition of wastewater fed to 20-day SRT biological reactor.

Synthetic wastewater stock		Reactor feed stock ^a			
		% PWW BOD	% PWW by volume		
Constituent	Wt. %		5-day SRT	10-day SRT	20-day SRT
Dextrose	41.8	5.26	1.4	2.8	5.6
Peptone	48.0	11.12	2.8	5.6	11.2
Yeast extract	1.8	33.33	5.6	11.2	28.0
Butyric acid	5.8				
MgSO ₄	1.0				
NH ₄ Cl	1.6				
FeCl ₃	0.02				

^aBOD of PWW = 20,000 mg/l; BOD of Syn. stock = 23,200 mg/l

Fig. 58. Summary of mixed liquor volatile solids in laboratory-scale biological reactors.

Fig. 59. Summary of chemical oxygen demand (COD) removal performance of laboratory-scale reactors used to treat pyrolysis wastewater.

These pilot plant observations suggest that the wastewater from Union Carbide's PUROXTM process can best be treated biologically when operating at SRT's of 10 days or greater and when blending no more than about 5% PWW by volume with another water stream, for example domestic sewage, prior to treatment. The 20-day SRT, 11% PWW by volume combination also provided reasonable treatment. Treatment at SRT's less than 10 days should be possible when adequate amounts of domestic wastewater are available for dilution.

Although anaerobic treatment has been successful with many industrial wastes and is attractive because of the methane formation and reduced sludge production, tests conducted by Dague [30] have shown that anaerobic treatment of PUROXTM pyrolysis wastewater is inefficient and requires considerable dilution and extremely long acclimation periods. Therefore, anaerobic digestion of pyrolysis wastewater was ruled out as an alternative treatment for this investigation.

Specific organic compounds, including the priority pollutants, were removed erratically by biological treatment (see Table 17). Generally the acid extractable priority pollutants were removed effectively while the base-neutral compounds were removed less effectively if at all. About 75% of the other acid and base-neutral extractable compounds were removed completely while about 25% remained in the biologically treated effluent. Removals of these unidentified organic compounds averaged 97.1% and 98% respectively for the acid and base-neutral extracts.

A second alternative for biologically treating PUROXTM process wastewater is to discharge the wastewater uniformly over each day of operation to a municipal wastewater treatment system. For a typical community, this would provide an average dilution ratio of about 1 part pyrolysis wastewater to 500 parts other municipal wastewater by volume. Increases in the concentrations

of various wastewater quality parameters effected by addition of the pyrolysis wastewater are shown in Table 19.

COD and BOD removals in laboratory-scale units usually exceeded 85% when the percentage of pyrolysis wastewater was held below toxic levels, and this agrees well with expected removals in full-scale activated sludge processes. This 85% removal should then apply to COD, BOD and priority pollutant removal upon addition of the pyrolysis wastewater to a municipal treatment system. Increases in combined effluent concentrations as a result of adding pyrolysis wastewater to a municipal sewerage system were then estimated conservatively as shown in Table 19. Also shown is the estimated contribution to effluent quality that would be expected if the effluent from an on-site biological treatment unit receiving prior biological treatment at a 1:18 dilution (5.6% PWV by volume) was added to the municipal system.

2.3.2.3. Chemical Treatment

The use of chemicals for precipitation and coagulation has had numerous applications in the field of wastewater treatment. Lime, aluminum salts, ferrous salts and ferric salts have all been used with varying degrees of success in treating a variety of industrial wastewaters for the removal of suspended solids, color, COD and BOD. On the basis of a literature review and the objectives of the present investigation, lime and alum were selected for treating both raw PUROXTM pyrolysis wastewater and the biologically treated effluent. These chemicals are used widely for treating wastewaters, such as papermill, petroleum refining and textile process wastewaters, having characteristics somewhat similar to the pyrolysis wastewater. Iron compounds were considered for use; however, it was felt that the difference between alum and iron compounds would be slight, and only alum was used.

Table 19. Effluent quality attainable using biological processes for treating PUROXTM pyrolysis process wastewater (using 85% removal capability).

Parameter	Untreated PWW, mg/l	Increase in municipal wastewater concentration at 1:500 di- lution, mg/l	Treatment system effluent, mg/l			Typical discharge standard mg/l
			On-site bio- logical treat- ment at 1:18 dilution	Direct dis- charge to municipal system	Discharge of 1:18 effluent to municipal system	
COD	40,000- 77,000	80-154	333-642	12-23	1.8-3.5	200+
BOD ₅	16,000 52,000	32-104	133-433	4.8-15.6	0.7-2.3	10-30
O-chlorophenol	57	0.11	0.48	0.017	0.003	N ^a
Phenol	300	0.60	2.50	0.090	0.014	N
Naphthalene	5	0.010	0.04	0.002	2.4×10^{-4}	N
Acenaphthylene	2.5	0.005	0.02	7.5×10^{-4}	1.1×10^{-4}	N
Fluoranthene	0.3	6×10^{-4}	0.003	9×10^{-5}	1.6×10^{-5}	N
^a N = not established						

The chemical treatment program consisted of treating a number of dilutions of PUROXTM pyrolysis wastewater with a wide range of chemical dosages. All tests were conducted on a laboratory scale using conventional flocculation test equipment [31]. Dilutions having 1.4, 2.8, 7, 50 and 100% PWV by volume were selected for testing. In actual practice, organic materials would be contributed by domestic or other wastewater to which the pyrolysis wastewater would be added. However, because of the difficulty in keeping a large volume of domestic wastewater from varying throughout the study and because a consistent dilution water was needed to maintain a high degree of sensitivity in organic analysis by mass spectroscopy and gas chromatography, distilled water was used for making the dilutions.

Lime or alum dosages ranged from 1,000 mg/l to 5,000 mg/l. The natural pH of the pyrolysis wastewater was about 4.1 and therefore it contained no alkalinity. Thus, it was necessary to add alkalinity to induce the formation of the precipitant species, as lime combines with alkalinity to form calcium carbonate and alum combines to form aluminum hydroxide. Sodium carbonate was used for this purpose and was added in amounts chemically equivalent to the coagulant dosage. The pH of the treated samples was adjusted after the addition of sodium carbonate and the coagulant using either concentrated sulfuric acid or 30% potassium hydroxide. Lime treated samples were adjusted to a pH of 10.0, while alum treated samples were adjusted to a pH of 5.5.

The importance of maintaining a constant pH is apparent when the ionization of compounds is considered. In the ionized state or when the $\text{pH} > \text{pK}_a$, compounds will not be adsorbed as readily as when the compounds are in the unionized state or when the $\text{pH} < \text{pK}_a$. Therefore, in order to compare the removal of individual compounds with respect to

the solids concentration, the pH was maintained constant throughout the series of tests for each coagulant.

In general, neither lime or alum treatment provided satisfactory removal of COD or BOD₅ (Table 20). About the best COD reduction that could be accomplished was 10 to 15% and little improvement was observed when using chemical dosages greater than 2,000 to 3,000 mg/l.

Organic priority pollutants were reduced to a greater extent than was COD, but removals generally averaged only about 50%. Removals seemed to be greater without dilution, which was unexpected because the adsorption capacity of the chemical precipitates should have been greater as the percentage of pyrolysis wastewater decreased. Those test results showing greater concentrations after treatment and adjustment for dilution than were present in the untreated wastewater reflect the poor test precision. This points out the need for improved procedures for extracting organics from wastewater samples.

A second series of tests was conducted in which lime or alum was used to treat the clarified effluent from a biological treatment unit. This biological reactor received a mixture of 5.6% PWV and 94.4% synthetic waste by volume giving a PWV/synthetic BOD ratio of about 18%. The reactor was operated at a 10-day SRT.

Lime treatment was found to produce the best results giving about 40% COD removal at a chemical dosage of 1,500 mg/l (Table 21). Additional lime dosages did not greatly improve the COD removal. Less than 30% COD removal was accomplished at alum dosages up to 5,000 mg/l.

Phenol was degraded in the biological system and did not appear in the effluent. Orthochlorophenol, naphthalene and acenaphthylene did

Table 20. Removal of organic materials from pyrolysis wastewater using lime or alum treatment.

Parameter	Untreated pyrolysis wastewater mg/l	Lime-treated effluent, mg/l						Alum-treated effluent, mg/l					
		1000 mg/l lime			3000 mg/l lime			1000 mg/l alum			3000 mg/l alum		
		1.4% ^b	7%	100%	1.4%	7%	100%	1.4%	7%	100%	1.4%	7%	100%
COD	40,000- 77,000	464 (33,143) ^c	2,551 (36,443)	36,258	459 (32,786)	2,510 (35,857)	34,558	425 (30,357)	2,495 (35,643)	36,210	410 (29,286)	2,391 (34,157)	33,175
BOD ₅ ^a	16,000- 52,000	182 (12,997)	1,000 (14,291)	14,219	180 (12,857)	984 (14,062)	13,552	167 (11,905)	978 (13,978)	14,200	161 (11,485)	938 (13,395)	13,010
O-chloro- phenol	57 --	1.1 (78)	3 (43)	33	1.0 (71)	1 (14)	15	0.4 (29)	1.1 (16)	37	0.4 (29)	1.0 (15)	17
Phenol	300	4.7 (336)	8 (114)	180	1.8 (129)	6 (86)	162	1.4 (100)	4.7 (67)	206	1.2 (86)	1.8 (26)	159
Naphthalene	4.8	1.1 (78)	0.4 (5.7)	11	0.3 (21)	0.2 (2.9)	4	0.2 (14)	1.1 (15)	2	0.2 (14)	0.3 (4.3)	2
Acenaphthylene	2.6	0.8 (57)	1.2 (17)	2	0.4 (29)	0.8 (11)	1	0.2 (14)	0.8 (11)	2	0.3 (21.4)	0.4 (5.7)	1
Fluoranthene	0.3	BDL	BDL	0.24	BDL	BDL	0.32	BDL	BDL	0.23	BDL	BDL	0.23

^a Assume COD/BOD₅ = 2.55.

^b % PWW by volume.

^c Numbers in parentheses are adjusted for dilution.

Table 21. Results of lime and alum treatment of effluent from a biological system receiving 5.6% pyrolysis wastewater by volume (20% by BOD).

Parameter	Untreated pyrolysis wastewater, mg/l	Lime treated effluent, mg/l			Alum treated effluent, mg/l		
		0 mg/l lime	1,500 mg/l lime	3,000 mg/l lime	0 mg/l alum	1,250 mg/l alum	2,500 mg/l alum
COD	40,000 to 77,000	3,696	2,202	2,107	2,025	1,840	1,765
O-chlorophenol	57	0.9	0.3	0.7	0	0	0
Phenol	300	0	0	0	0	0	0
Naphthalene	5	0.12	0.35	0.17	1.4	0.85	0.15
Acenaphthylene	2.5	0.36	0.76	2.05	0.9	0.44	0.48
Fluoranthene	0.3	0	0	0	0	0	0

appear in the biologically treated effluent and were not reduced appreciably by treatment with either lime or alum (Table 21).

None of the untreated samples exceeded the toxic threshold concentration and only barium and zinc exceeded typical pretreatment standards (Table 22). Although chemical treatment with lime or alum did not provide effective removal of organic materials, it did reduce most heavy metals. However, removal of zinc may require additional or alternate treatment since neither lime nor alum reduced its concentration to below typical pretreatment levels. Optimization of pH also could help provide greater efficiency of removal of specific metals.

2.3.2.4. Activated Carbon Treatment

Activated carbon adsorption for removal of organic materials from industrial wastewaters has been shown to be superior in many instances to biological treatment. It also has advantages over biological compounds and extreme conditions of pH, temperature, and shock loads. An additional advantage over both chemical and biological treatment methods is the absence of large amounts of sludge which often present expensive disposal problems.

An investigation of the treatability of PUROXTM pyrolysis wastewater using activated carbon was conducted by running batch and column treatment tests on the undiluted wastewater. Four different carbons were used, and their characteristics as provided by the manufacturers are given in Table 23. Adsorption isotherms were developed using batch tests and massive doses of powdered carbon. Column tests were conducted to simulate the performance expected of full-scale granular carbon facilities.

Table 22. Reduction of heavy metals in pyrolysis wastewater using lime or alum treatment.

Heavy metal	Concentration, mg/l					Water quality standards	
	Untreated pyrolysis wastewater	Lime treated		Alum treated		Toxic threshold, ^a mole	Industrial pretreatment, ^b mole
		1,000 mg/l	3,000 mg/l	1,000 mg/l	3,000 mg/l		
Arsenic	0.132	0.20	0.21	0.43	0.48	5	<1
Barium	<u>5.1</u>	0.046	0.021	0.089	0.076	100	<u><2.5</u>
Cadmium	<0.050	0.003	0.003	0.006	0.007	1	<3
Chromium	0.150	0.010	0.015	0.006	0.003	5	<8
Lead	1.25	0.10	0.056	0.028	<0.02	5	<3
Mercury	0.003	0.053	0.034	0.069	0.095	0.2	<0.1
Selenium	0.888	0.022	0.016	0.021	0.017	1	<1
Silver	0.01	<0.005	<0.005	<0.005	<0.005	5	<1
Copper	0.02	0.045	0.031	0.005	0.003	100	<6
Zinc	<u>65.8</u>	<u>8.3</u>	<u>5.9</u>	<u>14.0</u>	<u>10</u>	500	<u><8</u>
TOTAL (with zinc)	73.4	8.78	6.29	14.66	10.71		
(without zinc)	7.60	0.48	0.39	0.66	0.71		

^aBased on standards established by EPA under authority of RCRA.^bBased on typical pretreatment standards across the U.S.

Table 23. Characteristics of activated carbon used to treat PUROXTM pyrolysis wastewater.

Characteristic ^a	Amoco PX-21 (powdered)	National G-107 (granular)	Westvaco WV-G (granular)	Amoco GX-21 (granular)
Surface area, BET, m ² /g	2800-3500	1000-1100	1100	2943
Iodine number	2800-3000	--	1060	2670
Molasses decolorizing index	--	--	8.0	--
Total pore volume, cm ³ /g	1.4-2.0	0.72-0.80	--	1.634
Voids in packed bed (%)	--	--	40	--
Apparent density, g/cm ³	0.27-0.32	0.27-0.32	0.44	0.237
Freundlich isotherm coefficients ^b :				
K(g/g)	0.019	0.00002	0.00073	0.019
1/n	1.100	1.709	1.375	1.100
r	0.996	0.997	0.999	0.996

^aAll characteristics except isotherm coefficients were provided by the carbon manufacturers.

^b $\text{g COD/g carbon} = K(\text{COD})_{\text{eq}}^{1/n}$

Tests also were performed to determine the effectiveness of activated carbon for removing COD from the effluent from biological units receiving 5.6% pyrolysis wastewater by volume. This would be analogous to constructing a biological treatment system on site and using domestic wastewater to achieve the minimum required dilution.

Batch Treatment

Activated carbon did not reduce the concentration of COD and BOD₅ in raw pyrolysis wastewater to levels acceptable for discharge to a natural water course when using batch tests and massive doses of powdered carbon (Table 24). Priority pollutants were removed to a greater extent but not to levels expected to be suitable for direct discharge. Carbon doses as low as 5,000 mg/l were successful in reducing priority pollutants from biologically treated effluent but COD and BOD₅ levels still were too great for direct discharge.

Column Treatment

Column tests were conducted to determine the minimum effluent quality attainable with activated carbon. An undiluted sample of PUROXTM pyrolysis wastewater was fed to a column of AMOCO GX-21 activated carbon at a rate sufficient to provide 60 minutes of packed-bed contact time. Analysis of the column effluent indicated that high percentage removals occurred initially. However, column capacity deteriorated rapidly leaving an effluent having a COD that still was unacceptably high for direct discharge (Fig. 60).

Table 24. Results when treating raw pyrolysis wastewater and biologically treated wastewater with batch doses of powdered activated carbon (AMOCO PX-21).

Parameter	Batch carbon treated effluent, mg/l								
	Untreated pyrolysis wastewater				Biologically treated pyrolysis wastewater				
	Carbon =	0	10,000	40,000	90,000 mg/l	0	5,000	10,000	40,000 mg/l
COD		40,000-77,000	24,782	13,384	7,404	3,261	1,770	1,468	618
BOD ₅		16,000-52,000	9,718 ^b	5,249 ^b	2,904 ^b	1,279 ^b	694 ^b	576 ^b	242 ^b
O-Chlorophenol		57	54	9	2	0	BDL	BDL	BDL
Phenol		300	74	12	3	0.14	BDL	BDL	BDL
Naphthalene		4.8	0.7	BDL	0.3	0	BDL	BDL	BDL
Acenaphthylene		2.6	BDL ^a	BDL	BDL	1.85	0.64	0.06	0.15
Fluoranthene		0.3	BDL	BDL	BDL	0	BDL	BDL	BDL

^aBDL = Below Detection Limit.

^bUsing the ratio COD:BOD₅ = 2.55.

Fig. 60. Effluent quality from activated carbon column treatment of pyrolysis wastewater as related to column throughput.

2.3.3. Disposal of Sludges Produced Upon Biological Treatment of Pyrolysis Wastewater

Sludges produced in a laboratory-scale activated sludge unit operating at a 10-day SRT and receiving 5.6% of the feed BOD as pyrolysis wastewater by volume (about 20% by BOD load) were collected and air dried. The dry sludge was then pulverized and 6 grams were placed in a glass leaching column. A similar amount of sludge was placed in a second column containing 500 grams of an equal-weight mixture of top soil and acid-washed sand [15].

Five hundred milliliters of distilled water were added initially to the columns. Each day thereafter for 6 weeks, 250 ml of leachate were withdrawn from these columns and 250 ml of distilled water were added to the top of the column. The leachate samples were then analyzed for conventional and priority pollutants. A complete description of this column testing procedure is contained in Reference 15.

The test data indicated that the concentrations of conventional pollutant species in the column leachate were quite low (relative to standards) except for BOD (Table 25). This high BOD no doubt occurred because of continued decomposition of the organic material in the sludge, which normally would be stabilized to a greater extent than in the test sample. The soil column reduced the BOD significantly but initial concentrations of total and volatile dissolved solids were higher with soil than without soil. This apparent increase occurred because of differences in leaching between the test columns and control columns containing no sludge.

Table 25. Quality of leachates from sludges produced upon biological treatment of pyrolysis wastewater.

Parameter	Leachate quality				Water quality standards			Constit- uents of concern
	Without soil contact		With soil contact		Limits to ground- water, mg/l ^a	Toxic waste threshold, mg/l ^b	Low-rate, land application limits [33], mg/g	
	Peak conc mg/l	Average mg/g	Peak conc mg/l	Average mg/g				
CONVENTIONAL POLLUTANTS								
Biochemical oxygen demand	102	97	19	16.5	N ^c	N	N	
Total dissolved solids	67	111	118	132	500 ^d	50,000 ^d	N	
Volatile dissolved solids	32	59	65	70	N	N	N	
Chlorides	8.4	10.0	11.3	12.4	250 ^d	25,000 ^d	N	
METALS								
Arsenic	0.0045	0.0019	0.0053	0.0023	0.05	5	0.050	
Barium	0.490	0.23	0.200	0.117	1.0	100	N	
Cadmium	0.011	0.0037	0.055	0.018	0.01	1	0.015	*,?
Chromium	0.020	0.0067	0	0	0.05	1	1.0	
Lead	0	0	0.010	0.0033	0.05	5	1.0	
Mercury	0.0015	0.001	0.0007	0.0003	0.002	0.2	0.010	
Selenium	0.0064	0.0028	0.0033	0.0015	0.01	1	N	
Silver	0	0	0	0	0.05	5	N	
ORGANICS								
0-chlorophenol	(Acid)	0.24	0.447	0.81	0.980	N	N	N
2,4-dimethylphenol	(Acid)	0.03	0.047	0.21	0.323	N	N	N
2-chlorophenol	(Acid)	0.11	0.113	0.03	0.033	N	N	N
Naphthalene	(B-M)	0.20	0.133	0	0.040	N	N	N
Acenaphthylene	(B-M)	0.03	0.020	0	0	N	N	N
Bis-(2-ethylhexyl)- phthalate	(B-M)	0.49	0.467	0.11	0.213	N	N	N

^aBased on standards established by EPA or assumed equivalency to Safe Drinking Water Act standards.^bBased on standards established or proposed by EPA under authority of RCRA.^cN = no specific standards established.^dTentative or anticipated standards [14].

Both the metal and organic priority pollutant concentrations were quite low. The soil seemed to adsorb a number of the metals but the differences in concentrations were well within the precision of the test procedure. Acidic organic priority pollutants seemed to pass through the soil with little change in concentration while the base-neutral (B-N) compounds were attenuated considerably by the soil.

Because of different surface application rates and procedures, a more basic way to express leaching is in terms of the milligrams of leached constituent per unit weight of sludge. As shown in Table 25, the amounts of materials in the leachate are quite low and the metal concentrations and leached mass are considerably below the limits allowed in some states for land disposal of sludges [33]. No numerical land-disposal standards have been published for the organic priority pollutants.

This analysis indicates that, except possibly for organic priority pollutants for which no specific standards have been set, there appears to be no reason why sludges produced upon biological treatment of pyrolysis cannot be disposed of by land spreading or landfilling after proper conditioning by chemical or biological treatment.

2.3.4. Costs of Treating PUROXTM Pyrolysis Wastewater

Wastewater treatment costs were determined for three hypothetical municipalities considered to be served by a PUROXTM pyrolysis facility. A solid waste production rate of 4 lb/capita/day and a wastewater production associated with the pyrolysis facility of 100 gallons per gross ton of solid waste processed were considered to apply to each community.

The production of municipal sewage was considered to average 100 gal/capita/day. This provided a 1:500 ratio of pyrolysis system wastewater volume to other municipal wastewater volume.

Costs for influent pumping and flow equilization were determined using unit process construction costs presented in Construction Costs for Municipal Wastewater Treatment Plants: 1973-1977 [34]. Capital costs for carbon adsorption and carbon regeneration were obtained from Process Design Manual for Carbon Adsorption [35]. Costs for treating the pyrolysis wastewater in a municipal wastewater treatment facility were obtained from Analysis of Operations & Maintenance Costs for Municipal Wastewater Treatment Systems [36]. Costs were adjusted to third quarter 1979 (1979³) using EPA small city conventional treatment indices [37]. Operation and maintenance costs for labor, electricity and natural gas, and carbon makeup were estimated on the basis of flow and the amount of carbon to be regenerated. Present values were determined using a 20-year system life and an interest rate of 8%. Cost estimates were made for three treatment alternatives--on-site activated carbon treatment of undiluted pyrolysis wastewater, on-site treatment using 1:18 dilution of pyrolysis wastewater followed by carbon adsorption, and discharge of the pyrolysis wastewater to a municipal sewerage system. The detailed procedure for making this cost analysis is presented in Reference 31.

Carbon adsorption treatment of undiluted pyrolysis wastewater and effluent from on-site treatment was found to be quite costly even when carbon attrition losses were as low as 5% per regeneration cycle (Table

26). Costs for carbon treatment of on-site biological system effluent do not include the costs of the biological treatment.

The lowest cost treatment alternative was achieved when discharging the pyrolysis wastewater to a municipal wastewater treatment facility (Table 26). These costs are based only on typical operating costs per pound of BOD by activated sludge treatment using EPA published data [36]. No allowance was added to cover capital costs because of the low volumes of pyrolysis wastewater relative to the volume of other municipal wastewater. The unit costs for treatment include operation and maintenance costs associated with sludge disposal but no allowance was made for increased costs incurred because of adsorption of organic priority pollutants and heavy metals onto sludges.

The costs shown in Table 26 are expected to be the minimum because the treatment systems selected included the lowest number of units required and do not include costs of standby capacity.

Table 26. Comparison of costs for treatment of PUROXTM pyrolysis wastewater using alternative methods (1979³ dollars).

Solid waste processing rate (tons/day)	Cost basis	Carbon adsorption of undiluted PUROX TM pyrolysis wastewater		Carbon adsorption of biological system effluent		Discharge to a municipal treatment facility	
		Low ^a	High ^a	Low ^a	High ^a	Low ^a	High ^a
200	\$/ton	2.44	4.28	2.71	4.78	0.88	1.76
	\$/1,000 gal	24.40	42.85	27.11	47.81	8.79	17.57
1,000	\$/ton	2.21	4.06	2.46	4.52	0.88	1.76
	\$/1,000 gal	22.14	40.59	24.64	45.24	8.79	17.57
2,000	\$/ton	2.17	4.02	2.41	4.47	0.88	1.76
	\$/1,000 gal	21.72	40.17	24.11	44.67	8.79	17.57

^aLow and high costs based on 5% and 10% carbon attrition, respectively.

^bLow and high costs based on treatment costs of \$0.12/lb BOD₅ and \$0.24/lb BOD₅ discharged, respectively.

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2.4. BIOLOGICAL CONVERSION SYSTEMS

Biological conversion involves the decomposition of organic materials by anaerobic microorganisms to form methane and carbon dioxide. The conversion involves two steps: First, a group of facultative microorganisms, known as acid formers, convert the organic material to organic acids; and second, anaerobic methane-forming microorganisms decompose the organic acids to form a gas which is approximately 60% methane. The remaining gaseous materials include primarily carbon dioxide plus small quantities of mercaptans, hydrogen sulfide, hydrogen and traces of other organic gases. This gas can be burned directly or upgraded to approximate pipeline quality. These anaerobic biological reactions are used to convert refuse to methane by two different methods--biological reactors and landfill gas recovery.

2.4.1. Anaerobic Digestion

On June 13, 1975, Waste Management, Inc. of Oakbrook, Illinois, was selected by the Energy Research and Development Administration (now Department of Energy) to design, construct and operate an experimental solid waste-to-methane gas facility at Pompano Beach, Florida [39]. The design criteria for the system were based on research data compiled by Dr. John T. Pfeffer of the University of Illinois at Urbana-Champaign when using reactors of about 100 gallons each. Dr. Pfeffer also has acted as principal investigator for the Pompano Beach project. Separate supportive research has been conducted by the Institute of Gas Technology

in Chicago, Dynatech R/D in Cambridge, Massachusetts, and Systems Technology Corporation (SYSTECH) in Xenia, Ohio.

The location for the "proof-of-concept" project is at an existing shredding and landfill facility of Waste Management, Inc. in Pompano Beach. Municipal solid waste from the Pompano Beach area, combined with primary sludge from a wastewater treatment facility, is used. The municipal refuse is delivered to the facility where it is shredded by a 65 ton/hour primary shredding system (Fig. 61). Ferrous material is then separated magnetically. Shredded refuse is then transferred to a surge bin and into a rotating drum screen which helps to separate inorganic materials and grit from the primary shredded waste. From the drum screen, the shredded refuse is transferred to a secondary shredding system. The organic fraction of the secondary shredded material is then separated via air classification and a cyclone.

The light, organic fraction from the cyclone is transported to a blender for mixing with primary sludge. An organic loading of 50 to 100 tons per day is anticipated. A breakdown of feed constituents is listed in Table 27.

The digestion system consists of two, 50-ft-diameter concrete tanks equipped with fixed covers, a 23-ft operating level and a capacity of 240,000 gal in each reactor. The digesters will be operated in mesophilic and thermophilic modes. The basis of each operational mode is listed in Table 28.

Preliminary plans for mixing were based on using compressed digester gas, but research indicated that mechanical mixing probably would be required [40,41]. Therefore, mechanical mixers were installed.

BIOLOGICAL GASIFICATION OF REFUSE IN REACTORS

Fig. 61. Schematic diagram of anaerobic digestion system [38].

Table 27. Feed constituents for Pompano Beach digestion system [39].

Material	Tons per hour to each digester	Water input gal/T _{sw}
Shredded refuse @ 23% moisture	2.166	68 (new)
Primary sludge @ 5% solids	1.659	216 (new)
Hot water	5.288	724 (new)
Net water input		1,009
Nutrients (dry)		
Ammonium chloride	as required	--
Potassium Di-H phosphate	as required	--
Recycle filtrate	2.043	279 (recycle)
Water from compressor	0.60	82 (recycle)
Net recycle		361

Effluent slurry from the digester undergoes vacuum filtration for solid-liquid separation, and plans call for the recycle of the liquid filtrate and landfilling of the solids.

2.4.1.1. Water Use and Wastewater Production

Water for the facility is supplied from deep wells and from sewage sludge added for co-disposal. The blending operation will use the largest amount of water. Other uses of water include fire sprays, plant washdown and sanitary use.

The largest quantity of wastewater potentially originates in the solid-liquid separation system for the digester slurry effluent. Operating plans call for the recycle of this stream to the blending

Table 28. Basis of mesophilic and thermophilic operation [39].

Parameter	Mesophilic	Thermophilic
Feed	3" Shredded, Classified organics	3" Shredded, Classified organics
Recycle	100% Recovered water	100% Recovered water
Sewage sludge, % (dry solids basis)	2.5-5.0	2.5-5.0
Nutrients:		
Ammonium chloride	0.009 Ton/hour	0.009 Ton/hour
Potassium Di-H phosphate	0.001 Ton/hour	0.001 Ton/hour
pH	6.8±0.02	6.8±0.02
Feed solids concentration	8%-15%	8%-15%
Organic loading	20-40 TPD (0.45-0.9 lb/day- cu ft)	40-100 TPD (0.9-2.2 lb/day- cu ft)
Variable to be evaluated		
Temperature	95°F-112°F	122°F-140°F
Retention time	10-20 days	4-10 days
Level of mixing	To be evaluated	To be evaluated

operation. Any quantities not recycled will be disposed of by spray irrigation. Another primary source of wastewater is the leachate from the landfill. This leachate will be collected and disposed of with the slurry filtrate via spray irrigation over finished portions of the landfill.

Wastewater produced from washdown of the tipping floor and interior floor of the facility will be discharged to the spray irrigation system. Any excess water from fire fighting will be handled in a similar manner. Sanitary wastes from the plant will be discharged to an existing septic tank system. Storm water from the plant site will be channeled to the existing storm drains.

A smaller scale biological conversion system was operated by Systems Technology Corporation at Franklin, Ohio [41]. This project involved addition of pulped slurry from Franklin's wet pulping facility to a 100,000 gal anaerobic digester. About 10% by dry weight of the feed stock was sewage sludge. The unit was operated intermittently for about 18 months and the test program was designed to evaluate mixing requirements, energy balance, and process stability.

2.4.1.2. Wastewater Quality and Treatment

Wastewaters produced at the front-end processing plant at Pompano Beach are similar to those produced at other RDF processing plants and include washdown, bearing cooling and firefighting waters. These streams occur in such little volume or have so little chance of contamination that their discharge to a sanitary sewer should present no adverse problems with treatment nor should they produce adverse environmental impact using proper land disposal methods. Ideally, these wastewaters should be collected and added to the digester for slurry makeup water, thereby eliminating the need for separate disposal.

An assessment of potential wastewater treatment or disposal problems associated with the digester contents was made in two ways. First, the assumption was made that it may not be possible to recycle

digester supernatant at all times and that some type of treatment or disposal of the blowdown waters would be required. The treatability of these blowdown waters was determined using both conventional biological and advanced physical/chemical methods. Second, the potential for contamination of groundwaters with leachate produced upon land disposal or landfilling of the residual solids was determined using column leaching procedures.

Supernatant was collected from the Pompano Beach digesters when one of the two units was operating at a reduced loading of about 0.20 pounds of solids per day per cubic foot of volume (lb/day/cu ft) or about 20% of the design load. However, since the digester was fed erratically, the operating conditions possibly were not at equilibrium. Samples also were collected from a laboratory-scale anaerobic digester receiving a controlled mixture of solid waste having the composition shown in Table 29. The solids loading to the laboratory unit was about 0.15 lb/day-cu ft but this reactor had received feed daily for several months of continuous operation.

Analyses of these supernatant samples show high concentrations of soluble organics (Table 30). In both reactors, the heavy metals were adsorbed to the solids so that the soluble metals concentrations were quite low. Total Kjeldal and ammonia nitrogen concentrations were high because of the nutrient added to support biological growth.

Treatability of the digester supernatant was assessed using the laboratory-scale reactors. The filtrate that normally would be produced at the Pompano Beach facility was simulated by centrifuging the effluent slurry from the laboratory-scale reactors. This removed the solids

Table 29. Composition of feed material for laboratory-scale anaerobic digesters.

Constituent	Feed rate, ^a grams/day (dry weight)		Weight, %	Volume of liquid, ml
	Total	Volatile		
Kraft paper	26.8	23.7	39.4	--
Newsprint (unprinted)	23.2	21.4	35.5	--
Dog food (Purina)	10.2	6.6	10.9	--
Grass hay	8.3	6.0	10.0	--
K ₂ HPO ₄	0.2	--	--	--
NH ₄ Cl ₃	0.4	--	--	--
NaHCO ₃	3.5	--	--	--
Sewage sludge	~3.2	2.55	4.2	80
Absolute ethanol	--	--	--	15
Tap water				(add to total volume)
Total	75.8	60.25	100	833

^aReactor volume = 25 liters

that would be expected to be removed by fabric filters. As indicated in Table 30, the organic content of this simulated filtrate was much higher than that obtained from the Pompano Beach digester.

The filtrate was treated in laboratory-scale reactors as described previously for treating pyrolysis wastewater (see Fig. 57). This aerobic reactor was operated at a 10-day hydraulic and solids retention time. As indicated in Table 30, the soluble COD was reduced about 61%

Table Concentration of contaminants in wastewaters produced upon anaerobic digestion of municipal solid waste to produce methane gas.

Constituent	Pompano Beach digester slurry		Laboratory-scale digester slurry		Simulated filtrate		Aerobically treated effluent		Water quality standards		Constituents of concern
	Total, mg/l	Soluble, mg/l	Total, mg/l	Soluble mg/l	Total, mg/l	Soluble, mg/l	Total, mg/l	Soluble mg/l	Toxic threshold, ^a mg/l	Discharge to stream, mg/l	
CONVENTIONAL POLLUTANTS											
Chemical oxygen demand	<u>11,300</u>	<u>920</u>	<u>43,800</u>	<u>9,580</u>	<u>15,115</u>	<u>9,308</u>	<u>10,194</u>	<u>3,649</u>	N ^d	<u>200</u> ^{b,e}	*
Biochemical oxygen demand	--	--	--	--	<u>3,300</u>	<u>1,900</u>	<u>810</u>	<u>72</u>	N	<u>10-30</u> ^b	*
Suspended solids	7,000	--	--	--	3,023	--	4,439	--	N	<u>10-30</u> ^b	
Total solids	<u>11,100</u>	<u>4,100</u>	--	<u>6,776</u>	<u>15,331</u>	<u>12,308</u>	<u>13,452</u>	<u>9,013</u>	50,000	<u>500</u> ^c	*
Volatile solids	7,300	1,510	--	2,823	8,347	5,477	6,525	2,849	N	N	
Alkalinity	--	--	2,450	00	00	00	00	00	N	N	
Calcium	540	80	18	--	--	77	--	58	N	N	
Magnesium	69	53	44.3	--	--	47	--	40	N	N	
Sodium	536	549	816	--	--	880	--	835	N	N	
Potassium	--	--	672	--	--	2,220	--	2,120	N	N	
Chloride	--	--	--	--	--	--	--	--	25,000 ^e	250 ^{c,e}	
Sulfate	--	--	--	--	--	--	--	--	25,000 ^e	250 ^{c,e}	
Fluoride	--	--	--	--	--	--	--	--	140-240	1.4-2.4 ^c	
Nitrite + nitrate	0.4	0.4	--	--	--	0.97	--	<u>232</u>	<u>100</u> ^e	<u>10</u> ^e	*
Total Kjeldal nitrogen	298	--	1,140	--	586	--	251	--	N	N	
Ammonia nitrogen	<u>186</u>	<u>186</u>	<u>359</u>	--	<u>187</u>	--	--	<u>4.41</u>	N	<u>2-30</u> ^{+b}	
Total phosphate	--	--	--	--	--	--	--	--	N	N	
Iron	--	--	--	--	--	--	--	--	30 ^e	0.3 ^{c,e}	
Manganese	--	--	--	--	--	--	--	--	5 ^e	0.05 ^{c,e}	
Cellulose	0.86	--	30	--	--	--	--	--	N	N	
Lignin	2.50	--	39.1	--	--	--	--	--	N	N	
HEAVY METALS											
Arsenic	<u>0.070</u>	0.0073	--	--	--	--	--	--	5	<u>0.05</u> ^c	*,?
Barium	--	--	--	--	--	--	--	--	100	<u>1.0</u> ^c	
Cadmium	<u>0.1</u>	<0.05	0	0	--	--	--	--	1	<u>0.01</u> ^c	*,?
Chromium	0.4	<u><0.1</u>	3.37	<u><0.08</u>	<u>1.22</u>	0.08	--	--	5	<u>0.05</u> ^c	*
Lead	3.6	<u>0.1</u>	1.47	<u>0.08</u>	<u>0.56</u>	<0.08	--	--	5	<u>0.05</u> ^c	*
Mercury	--	--	--	--	--	--	--	--	0.2	0.002 ^c	

Table 30. Continued.

Constituent	Pompano Beach digester slurry		Laboratory-scale digester slurry		Simulated filtrate		Aerobically treated effluent		Water quality standards		Constituents of concern
	Total, mg/l	Soluble, mg/l	Total, mg/l	Soluble, mg/l	Total, mg/l	Soluble, mg/l	Total, mg/l	Soluble, mg/l	Toxic threshold, ^a mg/l	Discharge to stream, mg/l	
Selenium	0.01	<0.006	--	--	--	--	--	--	1	0.01 ^c	
Silver	0.7	0.1	--	--	--	--	--	--	5	0.05 ^c	
Copper	1.3	<0.2	2.06	0.72	1.18	0.72	--	--	100 ^e	1.0 ^{c,e}	
Zinc	24	<0.09	11.0	0.81	4.32	0.82	4.55	2.61	500 ^e	5 ^{c,e}	*,?
PESTICIDES											
Endrin	0								0.002	0.0002 ^c	
Landane	0								0.04	0.004 ^c	
Methoxychlor	0								1.0	0.1 ^c	
Toxaphene	0								0.05	0.005 ^c	
2,4-D	0								1.0	0.10 ^c	
2,4,5-T/Silvex	0								0.10	0.01 ^c	
Total PCB's	0.002 (0.02 mg/kg solids)	0.0065							10 mg/kg solids	N	

^aBased on limits for toxicity established for RCRA.^bBased on typical discharge standards for treated wastewaters.^cBased on standards set by Safe Drinking Water Act.^dNo specific standards established.^eTentative or anticipated standards [14].

and the soluble BOD₅ was reduced about 96%. The remaining soluble COD and soluble total and volatile solids were still quite high and exceeded anticipated standards for discharge to streams. The high concentrations of sodium and potassium reflect the use of salts of these elements for buffering and nutrient addition. The increased nitrite plus nitrate concentration in the aerobically treated effluent results from the conversion of ammonia nitrogen to nitrite and nitrate by biological oxidation. This caused the nitrite plus nitrate level to be quite high compared to discharge standards. Metals of concern include cadmium, chromium and lead but these are removed to a considerable extent by the solids produced in the aerobic treatment system and are not expected to present serious limitations to discharge.

2.4.1.3. Solids Disposal

Organic and inert solids not converted to methane gas must be disposed of by some acceptable means. The most likely method of disposal is by landfilling. By design, these solids will be removed from the digester slurry by fabric filtration and will consist of about 50 to 70% moisture by weight. Upon landfilling, the liquid carried with the solids and the percolation of water from other sources can cause a leachate to be produced.

The potential quality of this leachate and possible environmental control measures required to contain or treat the leachate was assessed using column leaching tests as described previously for ash disposal.

Peak and average concentrations and total leached mass over a seven-week column leaching test are shown in Table 31. Generally, concentrations of organic materials (COD, BOD₅ and volatile solids)

Table 31. Composition of waters leached from solids remaining after anaerobic digestion of solid wastes.

Constituent	Leachate quality concentration, mg/l		Total leachable, mg/g	Typical landfill leachate [42] mg/l	Water quality standards			Constituents of concern
	Peak	Average			Limits to groundwater ^a (MCL), mg/l	Discharge to stream, ^b mg/l	Toxic waste threshold, ^c mg/l	
CONVENTIONAL POLLUTANTS								
Chemical oxygen demand	<u>1205</u>	297	33.3	730-4,720	N ^d	>200	N	*
Biochemical oxygen demand	<u>1198</u>	<u>237</u>	<u>26.5</u>	120-2,980	N	<u>10-30</u>	N	*
Suspended solids	--	--	--	--	N	10-30	N	
Total dissolved solids	<u>4105</u>	<u>660</u>	74.0	1,880-5,040	<u>500</u> ^e	<u>500</u> ^e	50,000 ^e	*
Volatile dissolved solids	1414	253	28.4	1,092-2,930	N	N	N	
Alkalinity	1044	269	30.1	1,350-3,510	N	N	N	
Calcium	--	--	--	164-1,065	N	N	N	
Magnesium	--	--	--	39-128	N	N	N	
Sodium	--	--	--	128-840	N	N	N	
Potassium	--	--	--	51-600	N	N	N	
Chloride	<u>1295</u>	103	11.6	125-2,400	<u>250</u> ^e	<u>250</u> ^e	25,000	*
Sulfate	<u>2945</u>	<u>433</u>	48.6	5.3-250	<u>250</u> ^e	<u>250</u> ^e	25,000	*
Fluoride	<u>1.90</u>	0.20	0.02	0.27	<u>1.4-2.4</u>	<u>1.4-2.4</u>	140-240	*
Nitrite + nitrate	1.61	0.32	0.04		10 ^e	10 ^e	100	
Total Kjeldal nitrogen	320	69.33	7.75	8.7-494	N	N	N	
Ammonia nitrogen	123.1	23.5	2.63	0.3-427	N	N	N	
Total phosphate	163	55.9	6.26	0.8-4.7	N	N	N	
Iron	--	--	--	<u>1.6-30.3</u>	<u>0.3</u> ^e	<u>0.3</u> ^e	<u>30</u>	*
Manganese	--	--	--	0.6-7.8	0.05 ^e	0.05 ^e	5	*

Table 31. Continued.

Constituent	Leachate quality concentration, mg/l		Total leachable, mg/g	Typical landfill leachate [42], mg/l	Water quality standards			Constituents of concern
	Peak	Average			Limits to groundwater ^a (MCL), mg/l	Discharge to stream, ^b mg/l	Toxic waste threshold, ^c mg/l	
HEAVY METALS								
Arsenic	--	0	0	0.006-0.038	0.05	0.05 ^e	5	
Barium	--	0	0	0.08	1.0	1.0 ^e	100	
Cadmium	0.02	0.0014	0.0002	0.001-0.04	0.01	0.01 ^e	1	
Chromium	--	0	0	0.025-0.085	0.05	0.05 ^e	5	
Lead	0.09	0.014	0.002	0.023-0.065	0.05	0.05 ^e	5	
Mercury	--	0	0	--	0.002	0.002 ^e	0.2	
Selenium	--	0.0014	2.8x10 ⁻⁵	--	0.01	0.01 ^e	1	
Silver	--	0	0	--	0.05	0.05 ^e	5	
Copper	--	0	0	0.01-0.05	1 ^e	1 ^e	100 ^e	
Zinc	--	0	0	0.43-1.32	5 ^e	5 ^e	500 ^e	
ORGANICS								
(No pesticides, PCB's or organic priority pollutants found present)								

^aBased on standards established by EPA or assumed equivalency to Safe Drinking Water Act standards.

^bBased on standards established by EPA under authority of the Clean Water Act or assumed equivalency to Safe Drinking Water Act standards.

^cBased on standards established or proposed by EPA under authority of RCRA.

^dN = no specific standards established.

^eTentative or anticipated standard [14].

were higher than permitted for discharge and if collected from a landfill would require treatment. The levels of organic and dissolved solids are sufficiently high that total containment of leachate would be required in areas where groundwater contamination is likely to occur. Heavy metal concentrations in the leachate were quite low because the metals were adsorbed to and held by the solids.

The leachate produced from digested solids should present no greater problem than that produced upon landfilling the undigested solid waste. As shown in Table 31, the range of concentrations typically found in sanitary landfill leachates equal or exceed those from digested solids.

Costs for disposal by landfill are then expected to range from about \$5 to \$20 per ton dry weight of digested solids. This translates to about \$2 to \$6 per ton of raw solid wastes when considering that only about one third of the raw solid waste mass is converted to methane.

2.4.2. Landfill Gas Recovery

Recovery of methane gas from landfills is an occasional source of useful energy [43]. This has been done largely in landfills which have been in place for sufficiently long periods of time for anaerobic decomposition to convert the organic solids to methane. Attempts to recover this methane in large quantities were first made in 1971 at the Palos Verdes Landfill by the Sanitation District of Los Angeles [43]. This system consists of 18 wells placed over a 30 section part of a larger landfill. Each well consists of a perforated casing placed in a 36-inch

drilled hole. Gravel is packed around the casing. Each well is then connected to a header pipe that carries the collected gas to a central processing point (Fig. 62).

At Palos Verdes the gas is first compressed and then passed through a series of coolers and condensers. Some water is removed upon cooling and condensing but the gas is still saturated. A series of packed columns containing alumina gel, activated carbon and molecular sieves are used to remove any remaining water vapor, carbon dioxide, and other impurities. Dehydrated and purified gas is then compressed to about 400 psig for blending with natural gas.

The total amount of gas collected is about 2 million standard cubic feet per day (MMSCFD). About 50% of this is recoverable methane. [44].

Similar installations are operating or planned at a number of sites, predominantly in California (Table 32). The largest facility is at Monterey Park, California, where a plant designed to process 8 MMSCFD is under construction. At the Puente Hills Landfill, gas collection pipes are being laid in advance of new fill activity for future use.

2.4.2.1. Water Use and Wastewater Production

Little water is used at landfill gas recovery facilities except for washdown and sanitary purposes. Most condensers are air cooled and thus preclude water use.

Wastewater is produced at two basic points: (1) in initial compression and cooling stages where water vapor usually is condensed and collected mechanically; and (2) in the adsorption columns. The contaminants in the condensate water include small amounts of organics,

Fig. 62. Schematic diagram of gas recovery from a landfill (Palos Verdes, California) [38].

Table 32. List of operating and proposed facilities recovering methane gas from landfills [8,9].

Location	Owner	Use of methane	Design capacity/ throughput cu ft/day	Start-up date	Status
Azusa, California	Azusa Land Re- clamation Company	Sold to Reichhold Chemical Company	750,000	1978	Operational
ASCON Wilmington, California	Watson Energy Systems, Inc.	Oil refinery furnace	1,250,000	1978	Operational
City of Indus- try, Los Angeles, California	City of Industry	Public utility boiler fuel	600,000	1980	Operational
Mountain View, California	Pacific Gas and Electric Co.	Distributed in PG&E pipelines	650,000 (expanding to 3,500,000)	1979	Operational
Palos Verdes, California	Getty Synthetic Fuels, Inc.	Sold to Southern California Gas Company	720,000	1975	Operational
Sheldon-Arleta Los Angeles, California	City of Los Angeles	Burned in city power plant	2,800,000	1979	Operational

Table 32. Continued.

Location	Owner	Use of methane	Design capacity/ throughput cu ft/day	Start-up date	Status
Monterey Park, California	Ortloff Corp. and Getty Synthetic Fuels, Inc.	Sold to Southern California Gas Company	8,000,000	1979	Operational
Cinnaminson, Newark, New Jersey	Sanitary Landfill Corporation	Steel melting boiler fuel	250,000 (expanding to 1,000,000)	1979	Operational
Puente Hills, Whittier, California	L. A. Co. Sanitary District	Boiler fuel	250,000	1980	Testing in progress
Staten Island, New York	Getty Synthetic Fuels, Inc.	Sold to Brooklyn Union Gas Company	4,000,000+	1981	In design

probably organic acids, but relatively little inorganic materials (Table 33).

Quantities of wastewater produced during the clean-up of the gas reportedly are as low as 430 gallons per million standard cubic feet of raw gas [45]. This water is condensed from the water-laden gas and contains only about 1.1 mg/l total heavy metals. Organic materials condensed with the water produce a chemical oxygen demand of about 200 mg/l. This amounts to only 0.72 pounds of organic material per day. No detailed organic analysis has been reported for these wastewaters but their total concentration and volume are so low that they usually are returned to the landfills at a cost of less than \$0.10 per million standard cu ft of methane recovery.

Although a more comprehensive survey of water quality has not been found at this time, plans for analyzing the condensate taken at various stages of operating facilities are pending.

Because of the limited amount of water quality data, no firm conclusions can be drawn at this time concerning the water-related environmental control technology needed at landfill gas recovery facilities. Further assessment is in progress.

Table 33. Partial composition of condensate from a landfill gas recovery facility [46].

Constituent	Concentration, mg/l
pH	
Chemical oxygen demand	197
Suspended solids	85
Dissolved solids	61
Total solids	146
Total sulfide	<0.1
Cadmium	0.003
Chromium	0.01
Lead	0.02
Mercury	0.0004
Selenium	0.005
Silver	0.002
Copper	0.01
Zinc	1.04
Iron	1.62
Total phenols	0.13

REFERENCES

1. U.S. Congress, Solid Waste Disposal Act of 1965, Public Law 91-512, 91st Congress (1965).
2. U.S. Congress, The Resources Recovery Act of 1970, Public Law 91-512, 91st Congress (1970).
3. U.S. Congress, The Resources Conservation and Recovery Act of 1976, Public Law 94-580, 94th Congress (1976).
4. Johnson, L. D. and Young, J. C., "Water Use and Wastewater Production at Solid Waste Processing/Energy Recovery Facilities," Engineering Research Institute Report No. ISU-ERI-Ames-79005, Iowa State University, Ames, Iowa (September 1978).
5. U.S. Congress, Clean Water Act of 1977, Public Law 95-217, 95th Congress (1977).
6. U.S. Congress, Federal Water Pollution Control Act of 1972, Public Law 92-500, 92nd Congress (1972).
7. U.S. Environmental Protection Agency, "Hazardous Waste Management System," Federal Register, Vol. 45, No. 98, p. 33066 (May 19, 1980).
8. "ACTIVITIES in Resource Recovery," NCRR Bulletin, Vol. 10, No. 1 (March 1980).
9. Max, B. J., "Resource Recovery and Waste Reduction Activities," U.S. Environmental Protection Agency Report SW-432 (November 1979).
10. Levy, S. J. and Rigo, H. G., "Resource Recovery Plant Implementation: Guides for Municipal Officials--Technologies," U.S. Environmental Protection Agency Report SW-157.2 (1976).
11. Patton, P., Nashville Thermal Corporation, Nashville, TN, Personal Communication (October 15, 1976 and March 22, 1978).
12. Stierwalt, L., Martin-Drake Power Plant, Colorado Springs, CO, Personal Communication (March 26, 1980).
13. Graham, D. S., "Water Pollution Problems Associated with Coal-Fired Electrical Generating Plants," Paper presented at 1980 Annual Conference of the American Society of Civil Engineers, Portland, Oregon (April 1980).
14. U.S. Environmental Protection Agency, "Criteria for Classification of Solid Waste Disposal Facilities and Practices," Federal Register, Vol. 44, No. 179 (September 13, 1979).

15. Rademaker, A. D. and Young, J. C., "Analysis of Leachates from Solid Residues Produced at Municipal Solid Waste-to-Energy Facilities," Engineering Research Institute Report No. ERI-ISU-Ames-81062, Iowa State University, Ames, Iowa (October 1980).
16. Schoenberger, P. J. and Purdom, P. W., "Long-Term Chemical Leaching From Incinerator Residue," Proceedings, National Waste Processing Conference, American Society of Mechanical Engineers, 345 E. 47th St., New York, NY (1976).
17. Keairns, D. L., Sun, C. C., Peterson, C. H. and Newby, R. A., "Fluid-Bed Combustion and Gasification Solids Disposal," Proceedings, Workshop on Solid Waste Research and Development Needs for Emerging Coal Technologies, San Diego, CA. Sponsored by ASCE Power Research Council and Electric Power Research Institute, Palo Alto, CA (April 23-25, 1979).
18. Joensen, A. W., et al., "Evaluation of the Ames Solid Waste Recovery System. Refuse Processing Plant and Suspension-Fired Steam Generators," Final Report for U.S. EPA Project No. R803903-01-0. EPA Energy Systems Environmental Control Division, Cincinnati, Ohio (In Review, Sept. 1980).
19. Hove, M., Ames, Iowa, Municipal Power Plant, Personal Communication (July 1980).
20. Shannon, L. J., Shrag, M. P., Honea, F. I., and Bendorsky, D., "St. Louis/Union Electric Refuse Firing Air Pollution Test Report," U.S. Environmental Protection Agency Report No. 650/2-74-073 (August 1974).
21. Bassin, M., Teledyne National, Cockeysville, MD, Personal Communication (July 11, 1977).
22. Marsh, P., Black Clawson/Fibreclaim, Inc., Personal Communication (1978).
23. A. M. Kinney, Inc., "Franklin, Ohio's Solid Waste Disposal and Fiber Recovery Demonstration Plant, Volume I," National Technical Information Service Report No. PB-234-715 (1974).
24. A. M. Kinney, Inc., "Franklin, Ohio's Solid Waste Disposal and Fiber Recovery Demonstration Plant," Volume II, National Technical Information Service Report No. PB-234-716 (1974).
25. Systems Technology Corporation, "A Technical, Environmental and Economic Evaluation of the Wet Processing System for the Recovery and Disposal of Municipal Solid Waste," U.S. Environmental Protection Agency Report SW-107 (January, 1975).

26. Haverland, R., Systems Technology Corporation, Xenia, Ohio, Personal Communication (August 17, 1977).
27. Fisher, T. F., Kosbohn, M. L. and Rivero, J. R., "The PUROXTM System," Paper by Union Carbide Corporation, Linde Division, presented at the 80th National Meeting of the American Institute of Chemical Engineers, Boston, MA (Sept. 9, 1975).
28. Dinusson, K., Occidental Research Corp., Personal Communication (July 13, 1977).
29. Crane, R. H., Young, K., and Mathews, J., Union Carbide Corporation, Personal Communication (May 24, 1977) (July 15, 1977).
30. Dague, R. R. "Anaerobic Treatment of Liquid Wastes from Pyrolysis Processes." Final Report for U.S. Department of Energy Contract No. EC-77-S-02-4455 (Draft: September 1980).
31. Hall, D. M. and Young, J. C., "Physical/Chemical Treatment of Wastewaters from Pyrolysis Processes," Engineering Research Institute Report No. ISU-ERI-Ames-81063, Iowa State University, Ames, Iowa (October 1980).
32. U.S. Environmental Protection Agency, "Sampling and Analysis Procedures For Screening of Industrial Effluents for Priority Pollutants," Environmental Monitoring and Support Laboratory, Cincinnati, Ohio (April, 1977).
33. "Disposal of Municipal Sewage Sludges on Land," Code of Iowa, Chapter 33 (June 1978).
34. U.S. Environmental Protection Agency, "Construction Costs for Municipal Wastewater Treatment Plants: 1973-1977," EPA Report No. 430/9-77-015 [MCD-37] (May 1978).
35. U.S. Environmental Protection Agency, "Process Design Manual for Carbon Adsorption," U.S. EPA Technology Transfer Report (October 1973).
36. U.S. Environmental Protection Agency, "Analysis of Operations and Maintenance Costs for Municipal Wastewater Treatment Systems," EPA Report No. 430/9-77-015 [MCD-39] (May 1978).
37. U.S. Environmental Protection Agency, "EPA Small City Conventional Treatment Indices," U.S. EPA Publication WH-595, 3rd Quarter 1979.
38. The Aerospace Corporation, "Energy Recovery from Municipal Solid Waste, An Environmental and Safety Mini-Overview Survey." Aerospace Corporation Report No. ATR-76(7518)-7 (June 1976).

39. Waste Management, Inc., "Proposal for Energy Research and Development Administration Facility for the Production of Methane Gas from Urban Solid Waste," Waste Management, Inc., Oak Brook, IL (January 1976).
40. Brown, J. W., Pfeffer, J. T. and Liebman, J. C., "Biological Conversion of Organic Refuse to Methane." Report No. UILU-ENG-76-2021, University of Illinois, Urbana-Champaign, IL (November 1976).
41. Swartzbaugh, J. T. and Smith, R. B., "Evaluation of Mixing Systems for Biogasification of Municipal Solid Waste," Final Report for Department of Energy Project E(40-1)-5175 (July 1979).
42. Cameron, R. D. and Koch, R. A., "Toxicity of Landfill Leachates," Journal Water Pollution Control Federation, 52, 4, 760 (April 1980).
43. Wilkey, M. L., "U.S. Cities Recover Methane from Landfills," Compost Science/Land Utilization, p. 24 (Jan./Feb. 1980).
44. "Tapping Garbage for Pipeline Gas," Chemical Week, p. 20 (July 9, 1975).
45. Blanchet, M. J., "Start up and Operation of the Landfill Gas Treatment Plant at Mountain View," Proceedings of the Fifth Annual Research Symposium on Municipal Solid Waste: Resource Recovery, U.S. EPA Report No. EPA-600/9-79-0236 (August 1979).
46. Murphy, M., County Sanitation Districts of Los Angeles County, Los Angeles, CA, Personal Communication (June 1980).

APPENDIX A: PROJECT REPORTS

1. Johnson, L. D. and Young, J. C., "Water Use and Wastewater Production at Solid Waste Processing/Energy Recovery Facilities." Phase I Final Report. Engineering Research Institute Report No. ISU-ERI-Ames-79005, Iowa State University (September 1978).

This report contains results of on-site surveys of operating urban solid waste-to-energy facilities and makes recommendations for follow-up research needed.

2. Young, J. C., "Assessment of Biological Processes for Treating Pyrolysis Wastewaters." Unpublished Project Interim Report (April, 1979).

This report contains results of a study designed to treat wastewaters from Union Carbide's PUROXTM pyrolysis process by biological methods.

3. Rademaker, A. D., "Analysis of Leachates from Solid Residues Produced at Urban Waste-To-Energy Facilities." Master of Science Thesis, Iowa State University, Ames, Iowa (November 1979).

This report contains results of a study designed to determine the quality of leachates from ash residues produced at Nashville's mass-burning facility and the RDF facility at Ames, Iowa, sludges produced at the anaerobic digestion unit at Pompano Beach, Florida and sludges produced upon biological treatment of pyrolysis wastewaters.

4. Hall, D. M., "Physical/Chemical Treatment of Pyrolysis Wastewater." Master of Science Thesis, Iowa State University, Ames, Iowa (April 1980).

This report contains the results of a study in which wastewaters from Union Carbide's PUROXTM pyrolysis process were treated chemically and by activated carbon adsorption.

5. Rademaker, A. D. and Young, J. C., "Leachates from Urban Waste Recovery Operations." Paper presented at American Society of Civil Engineers National Convention, Portland, Oregon (April 14-16, 1980).

This paper contains a summary of the results from report No. 3 above.

6. Blount, S., "Treatment of Wastewaters from Anaerobic Digestion of Urban Solid Wastes." Master of Science Thesis, Iowa State University, Ames, Iowa (Completion expected November 1980).

This report includes results of tests designed to determine the impact of recirculation on anaerobic digestion and to determine the treatment needs of blowdown waters from these processes.

7. Johnson, L. D., "Tracing of Organic Priority Pollutants through Anaerobic Digesters Receiving Urban Solid Wastes." Doctor of Philosophy Dissertation, Iowa State University, Ames, Iowa (Report completion expected March 1981).

The purpose of this project is to determine the fate of organic priority pollutants as they pass through anaerobic digestion processes receiving urban solid wastes.

8. Harrold, D. E., "Solvent Extraction of Organic Priority Pollutants from Solid Waste Residues." Master of Science Thesis, Iowa State University, Ames, Iowa (Report completion expected March 1981).

Some preliminary tests indicated that conventional solvent extraction methods will not remove all organic priority pollutants from solid residues; this study will attempt to define the limits of these methods and to develop new and better methods.