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Oxygen-Enriched Coincineration of MSW and Sewage Sludge

Final Report

Air Products and Chemicals, Inc.
Allentown, Pennsylvania

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
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NREL technical monitor: Philip B. Shepherd

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EXECUTIVE SUMMARY

Cocombustion of dewatered sewage sludge with municipal solid waste (MSW) can be successfully retrofitted to a Waste-to-Energy (W-t-E) facility with enhancements from oxygen enrichment and a novel dual-fluid, sludge atomization nozzle. The oxygen-enriched cocombustion process has been developed by Air Products and Chemicals, Inc., and evaluated in a 6 ton per day (TPD) pilot facility. Cocombustion of 11 wt% dry sludge/MSW is achievable, without decreasing the MSW capacity of the furnace, and without changing important operating conditions such as combustion temperature, flue gas flow rate, and flue gas excess oxygen. This ratio of sludge to MSW far exceeds the 2 to 3 wt% dry sludge/MSW limit of conventional cocombustion technologies for dewatered sludges.

The effect of cocombustion on flue gas pollutants, and the heavy metal content of the bottom ash and fly ash was evaluated as part of the test program. From a detailed statistical analysis, we have concluded that there should be no increase in flue gas NO_x, relative to baseline, when oxygen and sludge are added as long as furnace temperature is maintained. Further testing is required to evaluate the effect of oxygen and sludge on SO_2. In some cocombustion tests SO_2 decreased relative to baseline, while in others SO_2 increased, leaving some uncertainty. What was found was that averaging uncontrolled SO_2 emissions, after sludge and oxygen were added, were consistently within the normal range of commercial WTE plants, and did not exceed 250 ppm (@ 7%O_2). The findings of this study showed no significant effect of oxygen-enriched cocombustion on the heavy metal content of the bottom and fly ashes.

The novel dual-fluid, sludge atomization nozzle differentiates this technology, and makes oxygen-enriched cocombustion superior to other cocombustion methods for dewatered sludges. Conventional sludge feed methods for dewatered sludge have included premixing the sludge and MSW in the MSW storage pit, conveying the sludge into the MSW feed chute, and distributing the sludge directly on the burning bed of MSW via a variety of elaborate mechanical means. These operations often result in incomplete sludge combustion, and are limited in sludge capacity due to decreasing combustion temperature. In order to successfully cocombust a significant fraction of sewage sludge relative to MSW using existing technologies, sludge must be thermally dried to approximately 90% solids. Alternately, the dual-fluid atomization nozzle effectively reduces dewatered sludge particle size, thereby improving combustibility, and eliminates the need for mechanical or thermal preconditioning. Sludge atomization represents a significant improvement over conventional processes to combust this difficult waste.

Oxygen-enriched cocombustion of MSW and sewage sludge is an attractive alternative to current sludge disposal methods, such as composting, land application, and landfilling, and can provide a long-term solution to the growing sludge disposal problem in the United States, as well as in Europe and Asia. Retrofitting a W-t-E facility for cocombustion requires relatively minor furnace modifications. Capital investment in sludge handling equipment is less than $0.25 MM for each daily ton of sludge (dry basis), and on-site oxygen supply costs range from $30 to $50 per ton depending on the quantity of oxygen required. The oxygen used in this process is low purity and low pressure tonnage oxygen, which is much cheaper than chemical grade liquid oxygen. At sludge disposal costs of $300/dry ton of sludge, oxygen-enriched cocombustion is competitive with the other sludge disposal technologies available.

In the United States, the best markets for this technology are areas like the northeast where exporting MSW for land filling is becoming increasingly limited, environmentally safe and easily implemented methods to dispose of sewage sludge are in demand since the enactment of the Ocean Dumping Ban Act (1988), and waste combustors are located within reasonable proximity (75 mile radius) of the wastewater treatment plants from which sewage sludge can be sourced. In highly populated and industrialized areas such as these, the sludge quantities available meet or exceed the required per capita generation relative to MSW (6 tons dry sludge for each 100 tons of MSW); the ideal market for cocombustion.

Besides the benefit of providing an additional facility revenue stream for the owner/operator of the W-t-E plant, oxygen-enriched cocombustion offers many benefits to the states or communities including this technology in their sludge management plan:

1. Enables communities to develop long-term, joint sludge and MSW management plans. Together with a recycling program, all wastes produced in a community can be handled at a single location.

2. Eliminates the need for highly populated/industrialized states to export their sludge to other states where landfill space is available.

3. Eliminates siting/permitting a grassroots sludge disposal facility, or reduces the demand for land suitable for application of compost or treated sludge.

1.0 INTRODUCTION

Federal regulations banning ocean dumping of sewage sludge coupled with stricter regulations on the disposal of sewage sludge in landfills have forced municipalities, especially those in the northeast United States, to consider alternate methods for disposal of this solid waste. Coincineration of municipal solid waste (MSW) and sludge has proven to be economically attractive for both Europe and Japan, but has not yet proven to be a viable sludge disposal technology in the United States because of a history of operational problems in existing facilities.

The most prevalent problem in coincinerating MSW and a dewatered sewage sludge (15 to 25% solids) is incomplete sludge combustion. Incomplete sludge combustion is primarily a function of sludge particle size, occurring when the surface of the sludge particle dries and hardens, while the inner mass is unaffected. This phenomenon is commonly referred to in the industry as the "hamburger effect."

In an effort to promote technology development in this area, Air Products and Chemicals, Inc. teamed with the U.S. Department of Energy (DOE) through the National Renewable Energy Laboratory (NREL) to evaluate a new process being developed for the disposal of a dewatered sewage sludge, "Oxygen-Enriched Coincineration of MSW and Sewage Sludge."

This report provides a comprehensive summary of the pilot demonstration test program for oxygen-enriched coincineration of MSW and sewage sludge. This report describes the pilot test facility, instrumentation, and methods of data collection and data analyses; describes how the tests were executed; and discusses the test results. Recommendations for the future development of this technology in the current marketplace are also provided.

1.1 Program Objectives

The pilot test to demonstrate oxygen-enriched coincineration of MSW and sewage sludge was executed at a small, pilot scale facility operated by Riley-Stoker Corporation in Worcester, Massachusetts. The pilot test was conducted in two phases: Phase I in January/February 1992 and Phase II in September 1992. The objectives of the pilot test were to:

- Determine the maximum ratio of dewatered sludge to MSW that can be coincinerated with oxygen-enriched air.
- Evaluate a variety of sludge feed and sludge distribution methods to optimize sludge combustibility.
- Determine the effect of oxygen-enriched coincineration on flue gas emissions and residual bottom and fly ashes.
- Determine the optimum ratio of oxygen to sludge for MSW and sludge coincineration.
- Evaluate the enhancement of the MSW combustion rate due to oxygen-enriched underfire air, and also evaluate the impact of overfire air enrichment on combustion efficiency.
- Verify the relationships between MSW, sludge and oxygen derived from heat and material balance calculations.

1.2 General Concept

The oxygen-enriched coincineration process enables the disposal of dewatered sewage sludge in an existing waste-to-energy plant without sacrificing MSW capacity, and with no change to important incinerator operating conditions such as combustion temperature, flue gas flow rate and flue gas excess oxygen concentration. The process utilizes a state-of-the-art sludge feed system that avoids the mechanical sludge feed problems detrimental to existing coincineration technologies, and guarantees complete sludge combustion. The key to the technology is the synergistic combination of oxygen-enriched combustion air with the high moisture content of sewage sludge. Oxygen enrichment enhances combustion kinetics, thus allowing more waste to be incinerated on the combustion grate. At the same time, the rise in combustion temperature which normally accompanies oxygen enrichment is tempered by the high moisture content of sewage sludge. A schematic of the process is shown in Figure 1-1.

The combination of enhanced combustion kinetics and combustion temperature control enables the coincineration of a higher sludge/MSW ratio than is possible without oxygen enrichment. Conventional coincineration of dewatered sludge, without sludge drying or supplemental fuel, is limited to a maximum of about 2 to 3 wt% dry sludge/MSW. Attempts to increase the sludge ratio beyond this range yields combustion temperatures too low to maintain complete combustion. With oxygen enrichment there is no limit to the possible sludge/MSW ratio based on energy balance or combustion temperature constraints. In practice, the maximum sludge/MSW ratio will be set by constraints such as available sludge feed and sludge distribution methods, and oxygen compatibility with combustion air ducts.

The oxygen requirement for this coincineration process is dependent upon the solids content of the sludge, the sludge disposal rate, and the heating value of the MSW with which it will be burned. Based on heat and material balance calculations, the oxygen requirement to codispose of dewatered sewage sludge ranges from 2 to 5 tons oxygen per ton of dry sludge, assuming the higher heating value (HHV) of MSW ranges from 3500 to 6000 Btu/lb and the solids content of sewage sludge ranges from 15 to 30 wt%.

1.3 Market Dynamics and Economics

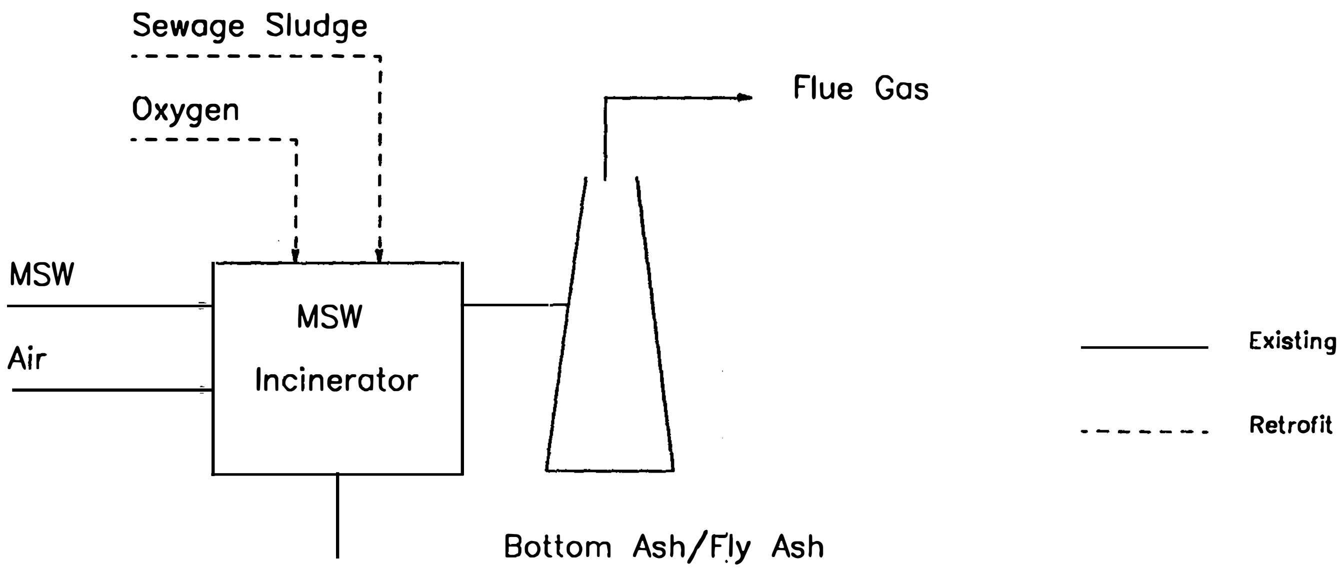
The disposal of sewage sludge is becoming increasingly more difficult, especially in the densely populated northeast United States. Conventional sludge disposal methods, including ocean disposal, incineration, composting, land application, and landfilling, are proving to be inadequate. Ocean disposal of sewage sludge was banned by the federal Ocean Dumping Ban Act of 1988. Incineration of sewage sludge is unpopular with the general public because of the perception that flue gas emissions and ash residue are harmful. Composting is considered the best disposal method for sewage sludge, however, it is costly, and if fully implemented, the amount of compost produced will far exceed demand. Land application is considered to be unacceptable due to the presence of heavy metals in the sludge, which may end up in the food chain. Finally, landfill space is becoming scarce.

Besides the technical shortcomings of these processes, the siting of any new sludge treatment process is proving to be extremely onerous due to factors such as aesthetics, odor and traffic. This is true even for relatively simple operations, such as sludge dewatering plants. Choosing a sludge management process will depend on a variety of factors including economics and the socio-political environment.

1.3.1 The Ocean Dumping Ban Act of 1988

The Ocean Dumping Ban Act created a discontinuity in sludge management practices. The burden of developing acceptable sludge management plans now rests on municipalities. This is a difficult problem for large municipalities in New York and New Jersey which have been ocean dumping sewage sludge since the 1920s. Lacking a long term solution, many such municipalities are shipping sludge to remote locations in Texas and Oklahoma at great expense.

Figure 1-1: Concept - Oxygen-Enriched Coincineration



The disposal of sludge in remote western locations currently costs over $1,000/dry ton for dewatered sludge containing 20% solids and 80% water. On a wet basis, this translates to $200/ton, which is approximately five times as high as the typical cost for disposing of MSW. It is expected that tipping fees (disposal costs) in the northeast will stabilize in the neighborhood of $400/dry ton; the market price for ocean disposal in the late 1980s. At $400/dry ton, there is ample potential to make both a profit and a meaningful contribution to society by developing new, innovative sludge management processes.

1.3.2 Sludge Disposal in Waste-to-Energy Plants

There is a synergy between sewage sludge and MSW both from a technical and market viewpoint. The chemical compositions of the two are similar when compared on a free water basis. Both sewage sludge and MSW can be made to burn with a large attendant reduction in volume and weight. Furthermore, both are generally considered to be non-hazardous in nature.

Considering the market on an aggregate basis, approximately 6 tons of sludge (dry basis) are produced for every 100 tons of MSW. Oxygen-enrichment enables coincineration of mechanically dewatered sludge in ratios exceeding 10 wt% sludge (dry basis) to MSW. Therefore, there are a large number of operating Waste-to-Energy (W-t-E) plants, especially in the northeast United States, that could coincinerate this quantity of sewage sludge with oxygen enrichment in place.

Retrofitting a W-t-E facility for coincineration is relatively simple and requires minimal capital investment. Also, the problems associated with siting and permitting a new sludge disposal facility are avoided. Preliminary economics for coincinerating 75 tons (dry basis) of dewatered sludge in a 750 ton per day (TPD) mass-burn incinerator are presented in Table 1-1. These economics include capital for the required modifications, capital and operating costs for the oxygen supply, and profit to the W-t-E plant. For the purpose of this estimate, the cost to produce oxygen has been included as a base facility charge in the operating costs. The cost of re permitting the W-t-E plant has been viewed as an initial investment and is included in the estimated capital cost.

Table 1-1
Preliminary Economics for Oxygen-Enriched Coincineration
(Basis: 750 TPD MSW Incinerator)

Sludge Disposal Rate (dry TPD)	75
Dry Sludge/MSW (wt %)	10
Oxygen Requirement (TPD)	260
Capital Cost ($MM)	18
Operating Cost ($MM/yr)	4
Sludge Disposal Cost ($/dry ton) (excluding dewatering and transportation)	300

The minimum sludge disposal cost, after allowing profit to the owner/operator of the W-t-E facility, is estimated at $300/dry ton. Sludge tipping fees greater than $300/dry ton simply increase the profitability of the process. At $300/dry ton, however, oxygen-enriched coincineration is competitive with the other sludge disposal technologies available.

Oxygen-enriched coincineration of MSW and sewage sludge would provide a cost-effective solution to the growing sewage sludge disposal problem in the United States.

2.0 DESCRIPTION OF THE TEST PLAN AND THE ACTUAL PILOT TEST SCHEDULE

The test plan for Phase I and Phase II outlined eight weeks of tests that would enable the evaluation of the oxygen-enriched coincineration technology. The tests were divided into four basic categories:

1. Baseline (MSW Incineration)
2. Oxygen-Enriched MSW Incineration
3. Oxygen-Enriched Coincineration of MSW and Sewage Sludge
4. Coincineration of MSW and Sewage Sludge without Oxygen-Enrichment.

Specific tests in each category were further differentiated by the level of oxygen enrichment, the zone for oxygen enrichment, the sludge solids content, and the sludge feed rate. A brief description of each test as defined in the test plan is given in Table 2-1.

The schedule of tests to be performed during Phase I and Phase II is given in Table 2-2. The test plan assumed three successful days of operation per week with a minimum of two to three runs completed each day. The goal was to complete 37 runs in Phase I and 16 runs in Phase II.

For clarification, a "run" is defined as the period of time during the operation of the pilot unit during which operating conditions remain unchanged and data is collected to support a specific test. The test plan defined the time for a run as three hours based upon an estimated grate residence time, however, in actuality test runs ranged from one to three hours since the unit reached steady-state conditions faster than expected.

Table 2-3 is the complete list of the runs that were actually performed during the test program. In Phase I, the pilot facility operated for a total of 17 days, however, on only 12 of these days was data actually collected in support of a run. Five days of plant operation were lost to initial shakedown of the unit, and/or mechanical equipment failures that caused the pilot unit to be shut down for repairs. (The problems encountered during the operation of the pilot unit are described in detail in Section 6.2). A total of 27 runs were completed, but as will be discussed in Section 7.0, only 14 runs were perceived as successful and used in the final analysis of this technology.

In Phase II, the pilot facility operated for seven days. Thirteen of the fourteen runs completed were successful. Four tests (M4, C4, C5, and C6) proposed in the initial plan were not performed during the pilot tests for the following reasons:

- Test M4—Sufficient burnout of the ash was attained with oxygen-enriched air in the combustion zone. There would have been no added benefit to oxygen-enriched air in the burnout zone.

- Tests C4, C5 and C6—The sewage sludge feed pump was capable of handling sewage sludge at 20% solids or less.

Table 2-1
Description of Tests

Test Description and Type	O2 Enrichment Zone (1)	% Oxygen	% Solids Sludge	Dry Sludge/MSW (wt %)
Baseline:				
O2 Enriched MSW Incineration:				
M1	Comb	Level 1		
M2	Comb	Level 2		
M3	OFA	Level 2		
M4	Comb/BO	Level 2		
M5	Comb	Level 3		
O2 Enriched Coincineration:				
C1	Comb		20%	5
C2	Comb		20%	7.5
C3	Comb		20%	10
C4	Comb		25%	5
C5	Comb		25%	7.5
C6	Comb		25%	10
C7 (Sludge Atomization Nozzle)	OFA		20%	7.5
C8 (Sludge Atomization Nozzle)	OFA		20%	10
C9 (Sludge Atomization Nozzle)	UFA		20%	10
Coincineration w/o O2 Enrichment:				
CC1			20%	7.5
CC2			20%	10

Notes -

1 Comb = Combustion Zone of Underfire Air, OFA = Overfire Air, BO = Burnout Zone of Underfire Air, UFA = Underfire Air

Table 2-2
Proposed Pilot Test Schedule

	Test Description		% Solids Sludge	No. of Runs
Phase I:				
WEEK 1				
Day 1	Start-up/Shakedown			
Day 2	Baseline			2
Day 3	Baseline			2
WEEK 2				
Day 1	O2 Enriched MSW Incineration	M1 & M2		2
Day 2	O2 Enriched MSW Incineration	M3 & M4		2
Day 3	O2 Enriched MSW Incineration	M5 & open		2
WEEK 3				
Day 1	O2 Enriched Coincineration	C1	20%	3
Day 2	O2 Enriched Coincineration	C2	20%	3
Day 3	O2 Enriched Coincineration	open		3
WEEK 4				
Day 1	O2 Enriched Coincineration	C3	20%	3
Day 2	O2 Enriched Coincineration	C4	25%	3
Day 3	O2 Enriched Coincineration	open		3
WEEK 5				
Day 1	O2 Enriched Coincineration	C5	25%	3
Day 2	O2 Enriched Coincineration	C6	25%	3
Day 3	O2 Enriched Coincineration	open		3
Phase II				
WEEK 1				
Day 1	Start-up/Shakedown			
Day 2	Coincineration w/o Oxygen Enrichment	CC1	20%	2
Day 3	Coincineration w/o Oxygen Enrichment	CC2	20%	2
WEEK 2				
Day 1	O2 Enriched Coincineration	C7	20%	2
Day 2	O2 Enriched Coincineration	C7 & C8	20%	2
Day 3	O2 Enriched Coincineration	C8	20%	2
WEEK 3				
Day 1	O2 Enriched Coincineration	C9	20%	2
Day 2	Open		20%	2
Day 3	Open		20%	2

Table 2-3
Actual Pilot Test Schedule

	Test Description	Sludge Feed System	Run No.
Phase I:			
WEEK 1			
20-Jan	Shakedown		
21-Jan	Shakedown		
22-Jan	Baseline		3A/3B
23-Jan	Baseline		4A/4B
WEEK 2			
27-Jan	Shakedown		
28-Jan	Shakedown		
29-Jan	Baseline/O2 Enriched MSW Incineration		7 A, B, C
30-Jan	Baseline/Coincineration	Sludge Pump	8 A,B
WEEK 3			
10-Feb	O2 Enriched MSW Incineration		9A
11-Feb	O2 Enriched Coincineration	Sludge Pump	10 A,B
12-Feb	O2 Enriched Coincineration	Sludge Pump	11A
13-Feb	O2 Enriched Coincineration	Sludge Pump	12 A,B
14-Feb	Baseline/O2 Enriched MSW Incineration		13 A,B,C
WEEK 4			
19-Feb	Baseline/O2 Enriched MSW Incineration		14 A,B,C
21-Feb	Shakedown		
WEEK 5			
26-Feb	O2 Enriched Coincineration	Atomization Nozzle	16 A,B,C
27-Feb	O2 Enriched Coincineration	Atomization Nozzle	17 A, B, C
Phase II:			
Week 1			
2-Sep	Baseline		20
3-Sep	Baseline		21
4-Sep	Baseline/Coincineration/O2 Enriched Coincineration	Atomization Nozzle	22 A,B,C
Week 2			
14-Sep	Baseline/O2 Enriched Coincineration	Atomization Nozzle	23 A,B,C
15-Sep	Baseline/O2 Enriched Coincineration	Atomization Nozzle	24 A,B,C
16-Sep	Baseline/O2 Enriched Coincineration	Atomization Nozzle	25 B,C
17-Sep	Coincineration	Atomization Nozzle	26B

3.0 PILOT FACILITY DESCRIPTION

3.1 Pilot Unit

The pilot combustor burns a nominal 450 pounds per hour (pph) of processed MSW. The furnace is a prototype of a full-scale Takuma system for mass-burning with dimensions of 17'-0" high and 11'-9" long. The reciprocating grate stoker has a total of eleven steps in each of the five grate rows and is 76" long by 36" wide. The combustion stoker grate is divided into three zones (drying, combustion and burnout) via the distribution of underfire air. A process and instrumentation diagram of the pilot unit is shown in Figure 3-1.

The furnace walls of the pilot unit combustor are refractory-lined and cooled by water-jacketed sections to simulate a waste heat boiler. The water flow and temperature rise are measured in each furnace section enabling heat balance closure. Flue gas exiting the furnace is cooled in two water-cooled chillers before entering the baghouse and wet scrubber for flue gas clean-up. Continuous monitoring of NO_x, O_2, CO, CO_2, SO_2 and total hydrocarbons (THC) is provided *prior* to the air pollution control equipment, which is not typical of W-t-E plant operations in the United States. Flue gas emissions in this pilot combustor, therefore, are more typical of an untreated flue gas.

Combustion air to the furnace is provided by a single blower which feeds air to the overfire injectors on the front and rear walls above the grate, and the three underfire air zones used for drying, combustion and burnout. The total air flow can be adjusted via a damper on the air blower to maintain a design flue gas excess oxygen concentration given a constant MSW feed rate. The distribution of the total combustion air between overfire and underfire air is manually adjusted with a damper in the underfire air header. The negative draft in the furnace is controlled with an induced draft fan upstream of the caustic scrubber.

Bottom ash is collected beneath each grate, as well as in a hopper as the ash falls off the burnout grate. When running the combustor at design MSW feed rates, the bottom ash hopper is emptied on-line as it reaches its capacity. Fly ash is captured at the furnace exit and the baghouse.

Start-up of the pilot combustor is dependent upon a natural gas fired burner located on the rear wall of the combustion chamber.

3.2 Sewage Sludge Feed System

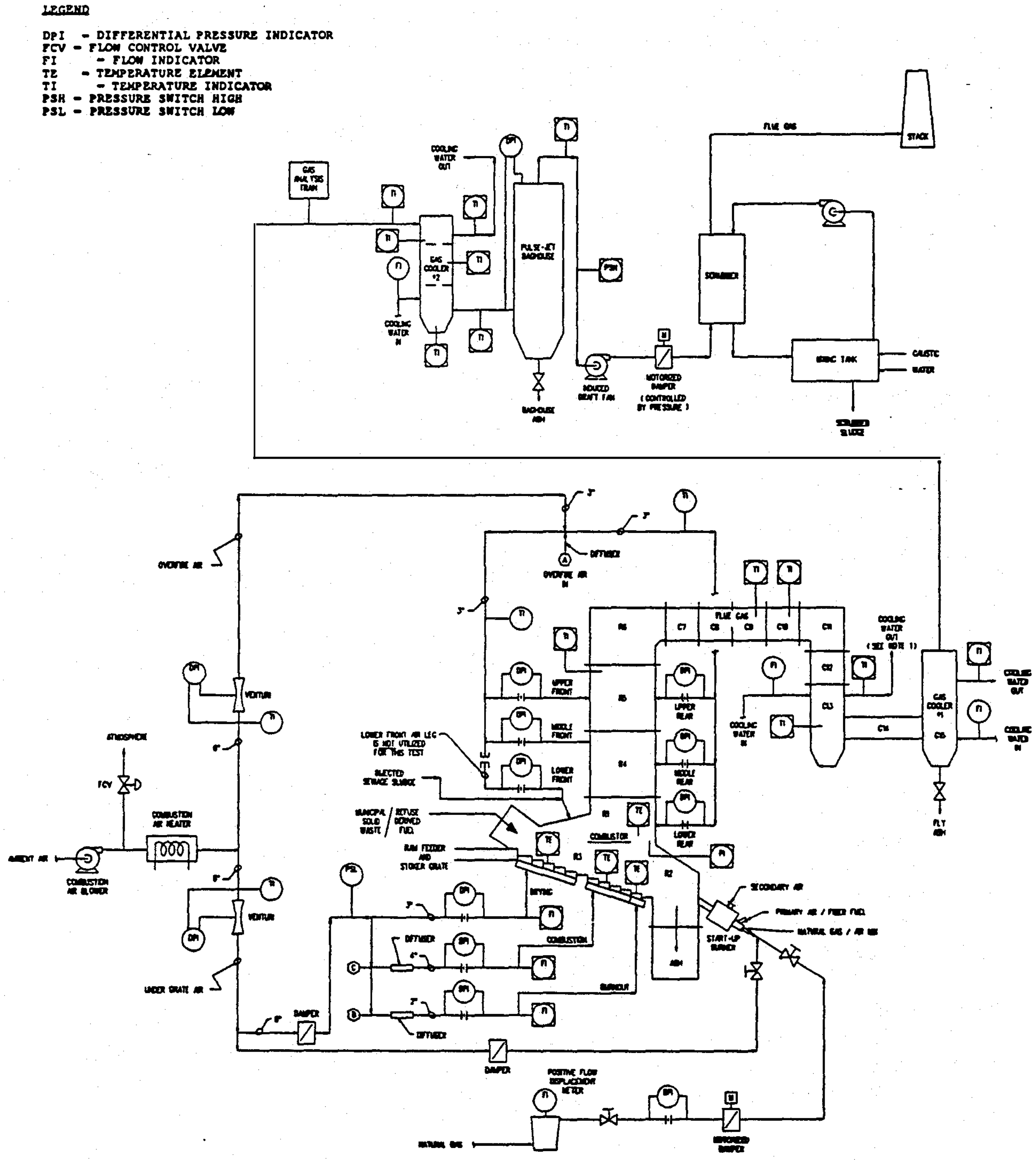
The pilot unit was modified to handle a dewatered sewage sludge as a second solid waste feed stream. Two feed systems were demonstrated during the pilot test which will be referred to hereafter as the Sludge Pump/ Sludge Extrusion Plate system and the Sludge Pump/Sludge Atomization Nozzle system. The latter system was developed towards the end of Phase I after it became apparent that complete sludge combustion was not being achieved via the sludge pump/sludge extrusion plate equipment.

3.2.1 Sludge Pump / Sludge Extrusion Plate Feed System

The sludge pump/sludge extrusion plate feed system was designed to feed a constant rate of dewatered sewage sludge directly to the grate in thin layers on top of the bed of refuse. The feed system consisted of a positive displacement variable speed pump, discharge piping, and sludge extrusion plates. A schematic of the feed system is shown in Figure 3-2. The sludge pump calibration curve generated for these tests is given in Appendix A-1.

As shown in Figure 3-2, the extrusion plate manifold was connected in the four overfire air ports in the roof of the furnace, otherwise referred to as the lower front overfire air (LFOFA) ports. The purpose of the sludge extrusion plate was to increase the evaporative surface area of the extruded sludge cake so that the sludge

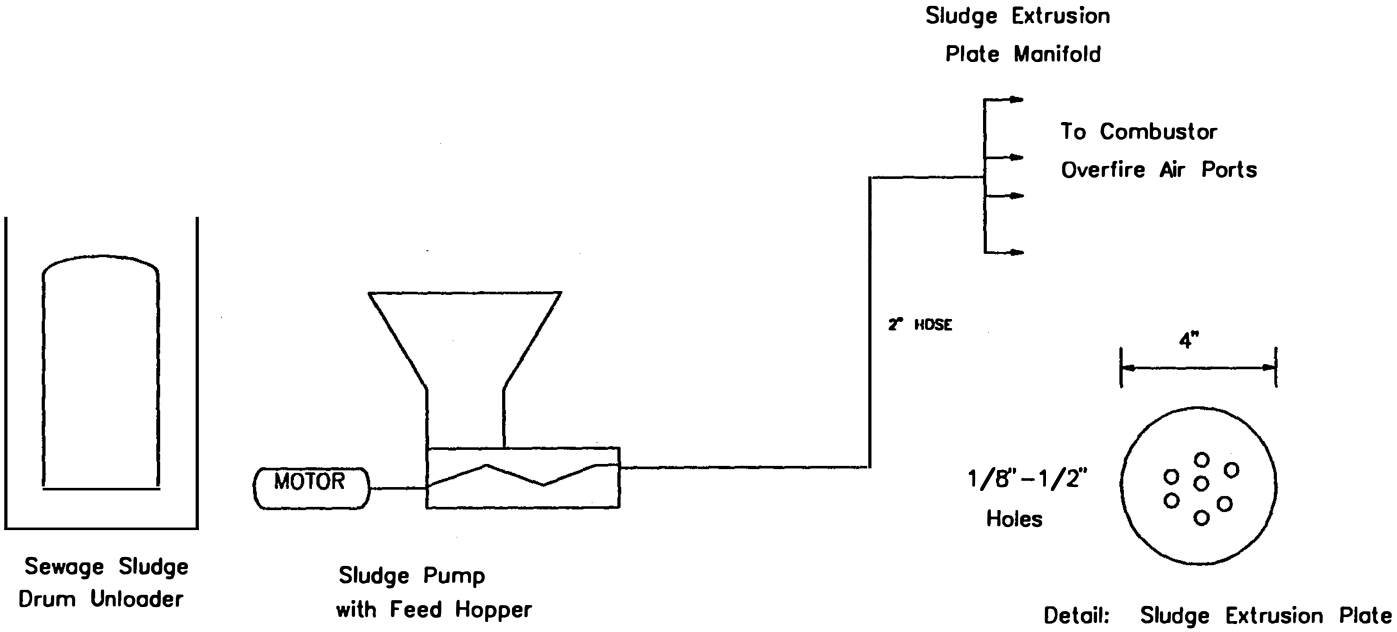
Figure 3-1: Process and Instrumentation Diagram - Pilot Combustion Facility



LEGEND

DPI - DIFFERENTIAL PRESSURE INDICATOR
FCV - FLOW CONTROL VALVE
FI - FLOW INDICATOR
TE - TEMPERATURE ELEMENT
TI - TEMPERATURE INDICATOR
PSH - PRESSURE SWITCH HIGH
PSL - PRESSURE SWITCH LOW

Figure 3–2: Sludge Pump/Sludge Extrusion Plate Feed System



would burn completely and not merely dry on the surface, thus producing the undesirable "hamburger effect." The diameter of the holes on the various sets of extrusion plates fabricated for this demonstration test ranged from 1/8" to 1/2".

3.2.2 Sludge Pump / Sludge Atomization Nozzle Feed System

In the second, and successful, sludge feed system demonstrated, the sludge extrusion plate manifold was replaced by a single sludge atomization nozzle. The sludge atomization nozzle was mounted in one of four lower rear overfire air (LROFA) ports. A schematic of the feed system is shown in Figure 3-3.

The sludge atomization nozzle was capable of significantly reducing the particle size of the sludge fed to combustor to the point where the sludge would completely combust. Compressed air or oxygen was used as the sludge's atomization fluid. For the pilot test, the recommended ratio of atomization gas to sludge ranged from one to two parts air to one part sludge, although the minimum atomization gas requirement was not determined. A copy of the sludge pump calibration curve generated with the sludge atomization nozzle is included in Appendix A-2.

3.3 Oxygen Enrichment Control System

Oxygen was introduced to the process through tie-ins to the overfire air, combustion and burnout zones of the underfire air, as well as to the sludge atomization nozzle. A schematic of the oxygen enrichment control system is shown in Figure 3-4. A cryogenic tank equipped with ambient air vaporizers supplied the purified oxygen (> 99.5% O_2).

The oxygen system consisted of two parallel flow systems containing oxygen diffusers, skid-mounted flow control piping, and field mounted oxygen analyzers to measure the concentration of oxygen in the enriched air stream. A copy of the calibration data for each of the flow skids is included in Appendix A-3. Oxygen could be fed to the combustor in each of the ways listed below, as outlined in the test plan:

1. Combustion zone underfire air only.
2. Combustion zone underfire air with burnout zone underfire air.
3. Overfire air only.
4. Combustion zone underfire air with overfire air.
5. Sludge atomization nozzle.

Figure 3–3: Sludge Pump/Sludge Atomization Nozzle Feed System

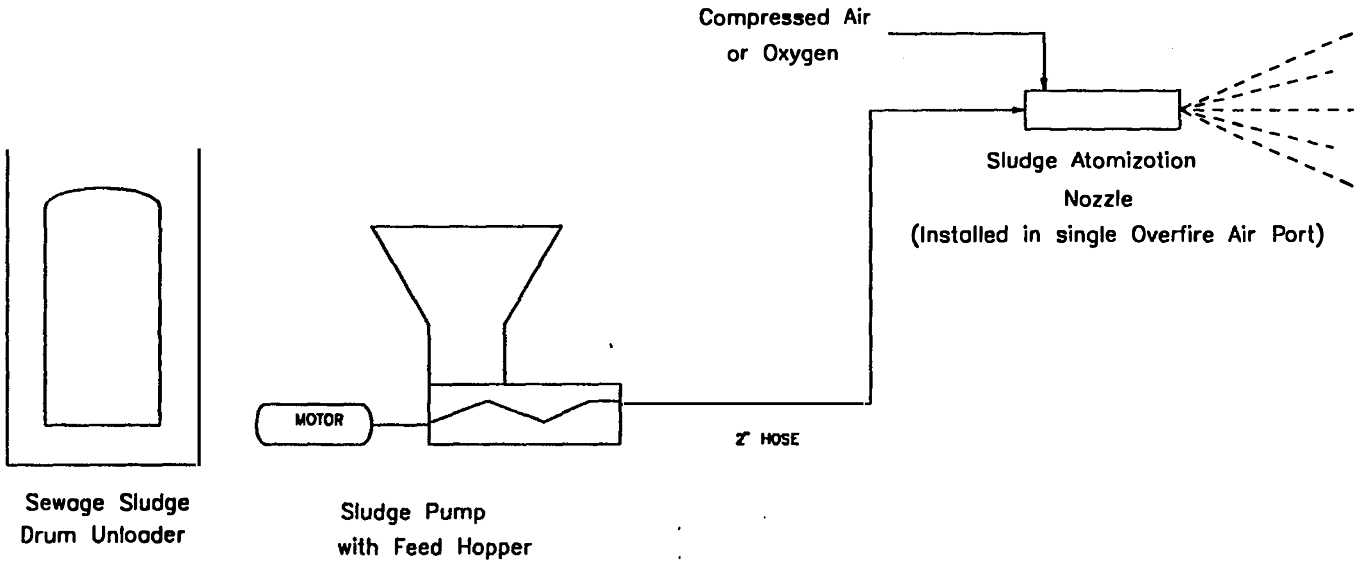
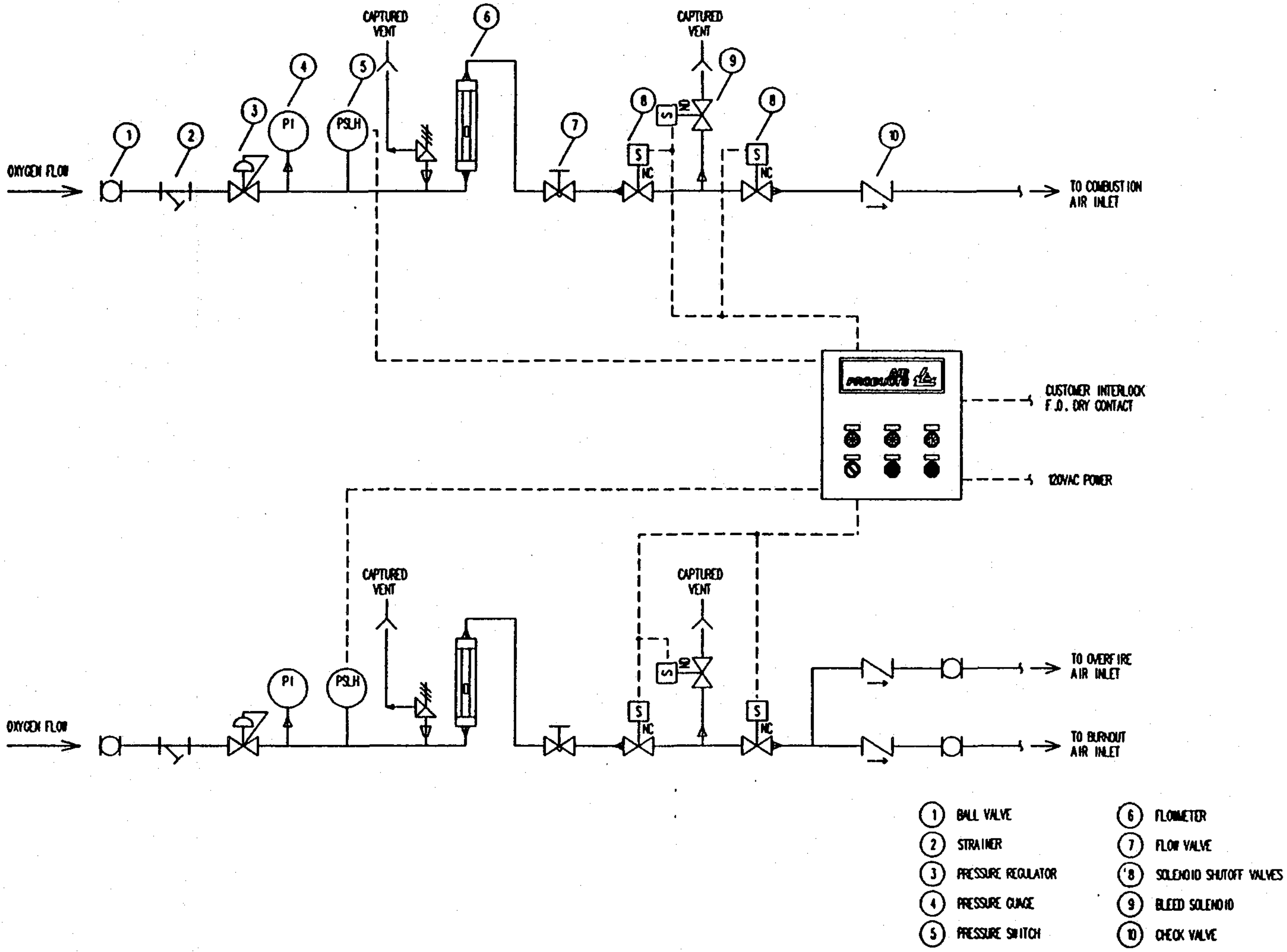


Figure 3-4: Primary Components of the Oxygen Flow Control Train



4.0 PILOT PLANT TEST DATA - HEAT AND MATERIAL BALANCE CONSIDERATIONS

Data was collected throughout the execution of the pilot test to ensure that the full impact of oxygen-enriched sludge coincineration on an existing MSW incinerator could be assessed. This section describes the data collected for the purpose of heat and material balance closure. Section 5.0 discusses the data collected for evaluating process emissions.

4.1 Data Acquisition System

All flow rates and temperatures schematically shown in Figure 3-1 were measured and automatically recorded by the data acquisition system connected to the computer. The most significant measured variables to complete the heat and material balance closure for the pilot unit are listed in Table 4-1.

Table 4-1
Data Acquisition System Process Data

Combustion Air Flow Rate:	Total Underfire Air	pph
	Total Overfire Air	pph
	Drying Zone Underfire Air	pph
	Combustion Zone Underfire Air	pph
	Burnout Zone Underfire Air	pph
Combustion Air Temperature	Underfire Air	° F
	Overfire Air	° F
Flue Gas Temperatures		° F
Baghouse Inlet/Outlet Temperatures		° F
Water-Jacket Inlet/Outlet Temperatures		° F

Note: Data recorded as two-minute averages (however, for initial test runs of Phase I, data collected on five-minute averages).

A copy of the calibration curves for underfire and overfire air flow rates measured via an orifice plate is included in Appendix B-1. These calibration curves were generated just prior to the start-up of the pilot test and were incorporated into the data acquisition system.

Other measurements requiring manual data collection for MSW, sewage sludge, flue gas, bottom ash/fly ash, and oxygen are described in Sections 4.2 through 4.4.

4.2 MSW and Sewage Sludge

4.2.1 MSW and Sewage Sludge Feed Rates

It was critical to the overall material balance for each test to measure the feed rates of both MSW and sewage sludge. As described in Section 3-2, calibration curves for the sludge feed pump were generated, and the pump was set to the desired sludge feed rate for each coincineration run. This calibration demonstrated that the feed rate was dependent upon the solids content of the sludge. To improve the accuracy of the heat and material balances, the actual sludge feed rate was also calculated from the weight of each batch of sludge emptied into the feed hopper and the corresponding time for the batch to be fed into the combustor.

The feed rate of MSW to the combustor was also calculated manually from a daily log indicating the weight of each batch of waste to be loaded onto the feed conveyor, and the time at which the first and last amounts of each batch were actually emptied onto the conveyor. From the daily data log, the average feed rate of MSW could be calculated for each run during each day given its starting time and ending time.

4.2.2 MSW and Sewage Sludge Composition

Ultimate and proximate analyses of MSW and sewage sludge were performed during the pilot test. Ultimate analysis yields the elemental composition of the sample by weight- S, C, H, N, and O. Proximate analysis measures the organic content of the sample (whether sludge or MSW) and is most often expressed as the percent of total solids (TS) that are volatile solids (VS). Volatile solids are organic compounds that are removed when the sample is heated to 1022°F under oxidizing conditions. Organic content is an important determinant of thermal value.

Four samples of the MSW used in Phase I and Phase II were analyzed; the results are shown in Table 4-2. The MSW physically resembled a mass-burn waste except that it was shredded and pre-processed to remove 50 to 60% of the ferrous metal. In actuality, the waste appeared to have a significant fraction of large-sized (greater than 6") ferrous and non-ferrous materials.

In addition to the ultimate and proximate analyses, the moisture content of the MSW was measured daily by drying a small sample of the waste in an oven. The daily MSW moisture data was important to establish the effect of inclement weather on the moisture content of the waste fed to the combustor. The moisture content of the MSW for each day of operation is given in Table 4-3.

The ultimate and proximate analyses of the sewage sludges coincinerated during Phase I and Phase II after the sludge pump/sludge atomization nozzle system was implemented are shown in Table 4-4. Sludge solids of these samples varied between 13 and 17%. The belt-pressed sewage sludge as received from the local wastewater treatment plant actually ranged between 22 and 25% solids. Water was manually added until the mixture was 20% solids or less, since the sludge feed pump performed better in this range.

4.3 Flue Gas

4.3.1 Flue Gas Flow

Flue gas flow is a critical data point in the material balance closure of the pilot unit. However, it was not included as one of the variables collected by the automated data acquisition system. To collect this data point the following method was used. A manual Pitot traverse measurement was taken in the straight run of 10" Schedule 80 pipe near the flue gas analysis sampling point, and between Gas Cooler #1 and Gas Cooler #2 (see Figure 3-1). A sketch of the flue gas duct cross-section indicating the location of each point of measurement is shown in Figure 4-1. As shown, the flue gas flow measurement is based on the pressure drop measured at twelve points within the pipe plus the center point. On the average, two to three Pitot measurements were taken during each pilot test run. A sample traverse Pitot flue gas flow calculation is given in Appendix B-2.

4.3.2 Flue Gas Moisture

Flue gas moisture was not only critical in the material balance closure of the pilot unit, but was also a data point needed to evaluate the effect of dewatered sewage sludge addition on the moisture content of a typical mass-burn incinerator flue gas. An apparatus was set up, as shown in Figure 4-2, that measured the flue gas moisture during each pilot test run. The apparatus consisted of a condensing coil, silica gel absorbent bed, and a dry gas meter. A sample calculation for the flue gas moisture measurement is given in Appendix B-3.

Table 4-2
Ultimate/Proximate Analysis of MSW - Phase I/Phase II

		ASTM Method	Sample 1 (Phase I)	Sample 2 (Phase I)	Sample 3 (Phase I)	Average Composition (Phase I)	Sample 1 (Phase II)
Proximate Analysis (as received)							
Moisture	wt %	D2961,D3173	17.97	31.49	25.37	24.94	28.02
Ash	wt %	D3174	17.91	19.85	13.98	17.25	11.75
Volatiles	wt %	D3175	55.69	42.58	52.70	50.32	51.16
Fixed Carbon	wt %	D3172	8.43	6.08	7.95	7.49	9.07
Ultimate Analysis (as received)							
Carbon	wt %	D3178	33.41	25.86	31.96	30.41	31.8
Hydrogen	wt %	D3178	4.65	3.50	4.39	4.18	4.42
Oxygen	wt %	D3176	24.91	18.55	23.51	22.32	23.31
Nitrogen	wt %	D3179	0.73	0.43	0.45	0.54	0.42
Sulfur	wt %	D3177	0.42	0.32	0.34	0.36	0.28
Ash	wt %	D3174	17.91	19.85	13.98	17.25	11.75
Moisture	wt %		17.97	31.49	25.37	24.94	28.02
BTU/Lb		D2015,D1989	5,381	4,399	5,642	5,141	5404

Table 4-3
Daily MSW Moisture

Date	Time	MSW Moisture, %	Date	Time	MSW Moisture, %
Phase I			***Phase II***		
Week 1: 23-Jan	8:10 AM	26.0	**Week 1:** 2-Sep	5:30 PM	28.0
	1:40 PM	35.0	3-Sep	10:45 AM	39.0
	4:45 PM	43.2		2:00 PM	41.0
			4-Sep		28.0
Week 2: 27-Jan	8:00 AM	41.0			
	6:15 PM	37.8	**Week 2:** 14-Sep	9:00 AM	23.8
28-Jan	8:00 AM	24.7		5:30 PM	28.8
	4:00 PM	28.6	15-Sep	8:00 AM	31.4
29-Jan	7:20 AM	24.4		4:00 PM	20.3
	6:10 PM	30.8	16-Sep	8:00 AM	20.6
30-Jan	9:50 AM	31.6	17-Sep	10:10 AM	29.4
Week 3: 10-Feb	4:00 PM	28.5	*Average*		29.0
11-Feb	10:00 AM	28.9			
12-Feb	11:40 AM	20.7			
13-Feb	9:00 AM	24.5			
	4:30 PM	38.6			
14-Feb	8:10 AM	29.3			
	1:30 PM	22.5			
Week 4: 19-Feb	9:00 AM	39.3			
	5:30 PM	26.3			
Week 5: 26-Feb	11:25 AM	38.1			
27-Feb	11:50 AM	31.6			
Average		31.0			

Table 4-4

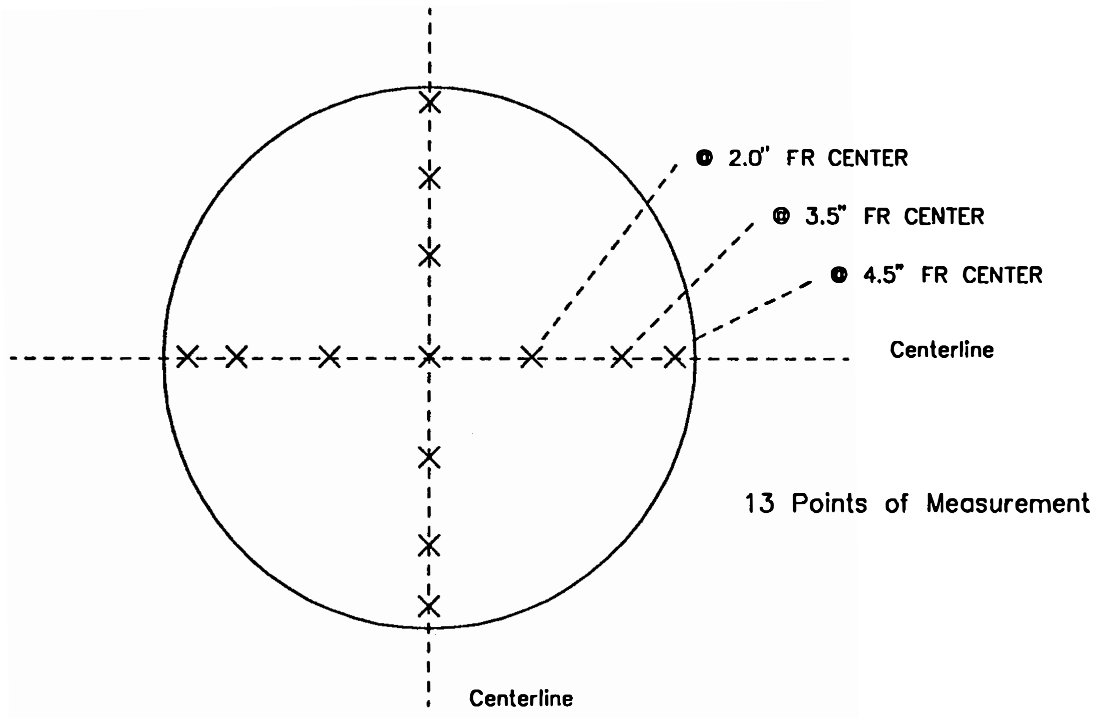
Ultimate/Proximate Analysis of Sewage Sludge - Phase I/Phase II

Parameter		Detection Limit	Run 16 A,B,C (Phase I)	Run 17 A,B (Phase I)	Run 17C (Phase I)	Run 22B (Phase II)	Run 22C (Phase II)	Run 23B (Phase II)	Run 23C/24B (Phase II)
% Solids			15.42	13.95	16.87	13.41	15.14	15.42	15.03
Proximate Analysis									
Moisture	wt %	0.01	84.58	86.05	83.13	86.59	84.86	84.58	84.97
Ash	wt %	0.01	3.15	3.37	4.36	4.19	4.47	4.54	4.16
Volatiles	wt %	0.01	12.06	10.58	11.33	8.70	10.67	10.68	10.51
Fixed Carbon	wt %	0.01	0.21	0.00	1.18	0.52	BDL	0.2	0.36
BTU/lb			1,255	1,107	1,474	1,022	1,204	1,238	1,217
Ultimate Analysis (dry)									
Carbon	wt %	0.01	44.19	41.39	41.45	40.29	40.01	40.63	40.2
Hydrogen	wt %	0.01	6.89	6.44	6.44	5.49	5.38	6.03	5.9
Oxygen	wt %	0.01	23.48	22.56	21.46	18.77	19.97	18.1	20.6
Nitrogen	wt %	0.01	4.33	4.76	4.53	3.46	4.11	4.27	4.87
Sulfur	wt %	0.01	0.71	0.69	0.64	0.75	0.81	0.76	0.86
Ash	wt %	0.01	20.43	24.16	25.48	31.24	29.72	30.21	27.67
BTU/lb			8,137	7,938	8,739	7,617	7,950	8,036	8,099
Ultimate Analysis (wet)									
Carbon	wt %		6.81	5.77	6.99	5.40	6.06	6.27	6.04
Hydrogen	wt %		1.06	0.90	1.09	0.74	0.81	0.93	0.89
Oxygen	wt %		3.62	3.15	3.62	2.52	3.02	2.79	3.10
Nitrogen	wt %		0.67	0.66	0.76	0.46	0.62	0.66	0.73
Sulfur	wt %		0.11	0.10	0.11	0.10	0.12	0.12	0.13
Ash	wt %		3.15	3.37	4.30	4.19	4.50	4.66	4.16
Moisture	wt %		84.58	86.05	83.13	86.59	84.86	84.58	84.97
Chloride	ppm	40	66	57	66	450	670	390	250

Table 4-4 (Continued)
Ultimate/Proximate Analysis of Sewage Sludge - Phase I/Phase II

Parameter		Detection Limit	Run 24C (Phase II)	Run 25B (Phase II)	Run 25C (Phase II)	Run 26B (Phase II)
% Solids			13.32	14.62	13.45	16.85
Proximate Analysis						
Moisture	%	0.01	86.68	85.38	86.55	83.15
Ash	%	0.01	3.59	3.69	4.07	4.34
Volatiles	%	0.01	9.53	10.93	9.38	12.2
Fixed Carbon	%	0.01	0.20	BDL	BDL	0.31
BTU/lb			1,082	1,181	1,113	1,325
Ultimate Analysis (dry)						
Carbon	%	0.01	40.22	40.80	40.36	45.48
Hydrogen	%	0.01	5.82	5.85	5.77	6.67
Oxygen	%	0.01	21.01	22.33	17.55	17.32
Nitrogen	%	0.01	5.15	5.03	5.25	4.12
Sulfur	%	0.01	0.85	0.75	0.86	0.65
Ash	%	0.01	26.95	25.24	30.21	25.76
BTU/lb			8,127	8,072	8,273	7,862
Ultimate Analysis (wet)						
Carbon	%		5.36	5.96	5.43	7.66
Hydrogen	%		0.78	0.86	0.78	1.12
Oxygen	%		2.80	3.26	2.36	2.92
Nitrogen	%		0.69	0.74	0.71	0.69
Sulfur	%		0.11	0.11	0.12	0.11
Ash	%		3.59	3.69	4.06	4.34
Moisture	%		86.68	85.38	86.55	83.15
Chloride	ppm	40	630	56	230	63

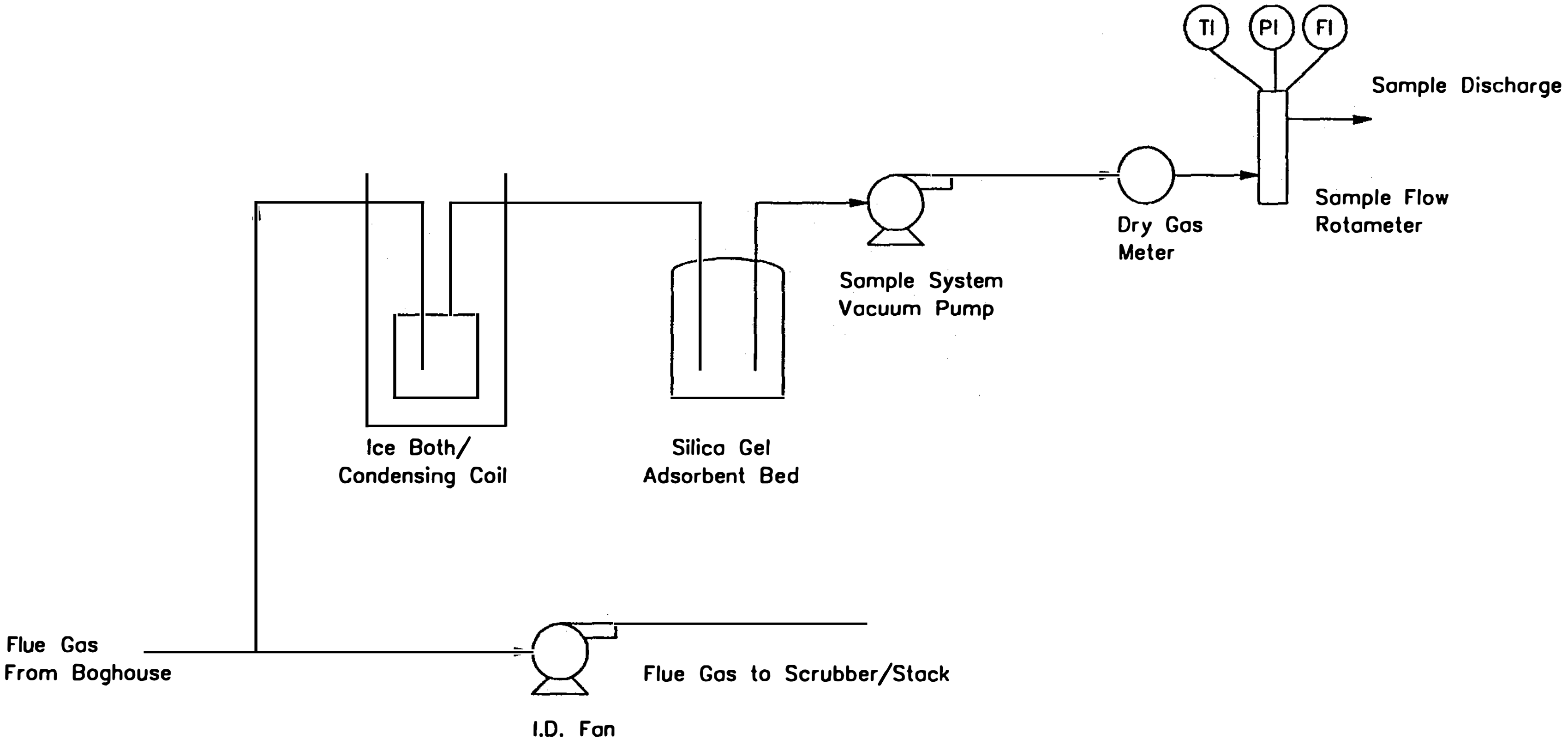
Figure 4–1: Flue Gas Flow Traverse Pitot Measurement



Cross–section of Flue Gas Duct

(Schedule 80 Pipe – 9.75" I.D.)

Figure 4–2: Flue Gas Moisture Apparatus



4.4 Bottom Ash and Fly Ash

4.4.1 Bottom Ash and Fly Ash Carbon

As discussed in Section 3.1, bottom ash and fly ash are collected as separate waste streams. Samples of bottom ash and fly ash were collected during each run and analyzed for unburned carbon.[1] The carbon content of the ash was indicative of the extent to which combustion on the grate was occurring, and was also a critical data point in the material atom balance for each run.

The sampling procedure for bottom ash and fly ash differed due to the significant difference in the quantities of each ash type produced. For example, after 10 hours of operation, the total fly ash collected from the combustor was less than 50 pounds, whereas the total bottom ash ranged from 600 to 800 pounds.

Bottom ash sampling was performed by compositing samples taken from the ash hopper throughout the day, or during a one- to three-hour test run. It was most convenient to take samples when the bottom ash hopper was being emptied on-line after the hopper reached its capacity. Because of the difficulties in obtaining samples on-line, it was only possible to collect a single representative grab sample for the short runs.

Fly ash samples were not composited in order to obtain a representative sample. In most cases, fly ash samples were collected at the end of each test day since it was difficult to collect these samples on-line, and the amount of fly ash produced after only a one- to three-hour run was very small.

4.4.2 Calculating the Non-combustible Fraction of the Solid Waste Feed

The weight of the total collected bottom ash and fly ash was recorded each day. The total weight of the bottom ash and fly ash divided by the total weight of MSW and sludge fed to the unit that day, represents the non-combusted fraction of the solid waste feed. The ash data was used to verify the results of the MSW ultimate and proximate analyses, and for heat and material balance closure .

A significant increase in the ash collected during a single day provided immediate feedback on the extent of combustion that had being achieved. This information proved very valuable during the coincineration runs when the sludge feed pump/sludge extrusion plate feed system was in place. During these runs, the non-combusted fraction of the solid waste feed increased 2 to 3% over that measured during the baseline test phase, indicating that sludge was not being combusted completely.

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[1] Perkin Elmer Method

5.0 PLANT TEST DATA - ENVIRONMENTAL CONSIDERATIONS

In addition to evaluating waste capacity and heat and material balance closure, it was important to collect data during the pilot test to evaluate this technology's effect on the two major waste streams produced via the mass-burn incinerator: flue gas and ash. Specifically, the heavy metals content of the residual ash and the concentration of the pollutants CO, NO_x, SO_2, HCl and THC in the flue gas were the focus of this study.

Sections 5.1 through 5.3 describe the provisions made in the analysis of the coincineration process to measure any changes to these waste streams, and the required modifications made to the pilot facility.

5.1 Flue Gas Emissions

5.1.1 Continuous Emissions Monitoring System (CEMS)

As part of the existing instrumentation installed on the pilot facility, flue gas O_2, CO_2, CO, NO_x, SO_2 and total hydrocarbons (THC) were measured in a continuous emissions monitoring system (CEMS). This data was retrieved by the data acquisition system on two-minute averages.

As shown in Figure 3-1, the flue gas sampling point is located upstream of the baghouse and caustic scrubber. The pilot facility was not equipped to monitor emissions after any flue gas clean-up equipment. The effect of oxygen-enrichment and sewage sludge on the emissions of the pilot combustor, therefore, were evaluated by comparing any changes in the untreated flue gas relative to the baseline run data.

Appendix C-1 describes the flue gas analyzers including make, type and accuracy. Instrument calibration was performed at the beginning and end of each test day, as well as one or two times during the day.

5.1.2 Flue Gas HCl Analyzer

An on-line HCl flue gas analyzer was retrofitted to the pilot unit for Phase I to evaluate the effect of chloride containing compounds in the sewage sludge on hydrochloric acid (HCl) stack gas emissions from a MSW incinerator.

The sampling point for the Thermoelectron Model-15 HCl Analyzer was located between Gas Cooler #2 and the baghouse (see Figure 3-1). Again, the flue gas at this point is untreated, and the effect of oxygen-enrichment and sewage sludge on HCl emissions is measured relative to the baseline HCl emissions. The data was retrieved on the data acquisition system. The HCl analyzer was calibrated at the same frequency as the other CEMS instruments.

Appendix C-2 contains a description of the equipment used for this analysis, the HCl analyzer, dilution probe and probe heater. Flue gas HCl was not measured in Phase II because the costs associated with this measurement did not justify the benefits of additional HCl data.

5.2 Bottom Ash and Fly Ash

It was important in the pilot demonstration test to address any impact coincineration with oxygen enrichment would have on the heavy metals content of the residual ash from a MSW incinerator. Bottom ash and fly ash are currently disposed of in landfills, however, the potential leachability of certain heavy metals, such as lead and cadmium, may be a concern.

TCLP (Toxicity Characteristic Leaching Procedure) testing of the fly ash was not conducted. The TCLP is a test that addresses the leachability of toxic constituents from MSW ash if it were to be disposed of in a landfill.

In the pilot unit, fly ash is collected from the baghouse which is located before the scrubber. This arrangement is the reverse of commercial installations where the particulate removal device (baghouse or ESP) is usually preceded by a dry scrubber which injects lime slurry into the flue gas for acid gas removal. Since the pilot unit fly ash is not contacted with a sorbent prior to removal, it was not considered representative of fly ash from a W-t-E facility, and the TCLP data would have been of limited use.

Each sample of bottom ash and fly ash collected was analyzed[2] for the following eight heavy metals regulated by the Resource Conservation and Recovery Act (RCRA):

Arsenic (Ar)
Barium (Ba)
Cadmium (Cd)
Chromium (Cr)
Lead (Pb)
Mercury (Hg)
Selenium (Se)
Silver (Ag)

The concentration of chlorides and sulfates were also measured.[3]

5.3 Sewage Sludge

To complete the analysis of heavy metals and chlorides in the pilot test, the samples of sewage sludge coincinerated when the sludge pump/sludge atomization nozzle feed system was in place were analyzed for the eight RCRA metals listed above, as well as for chlorides. This data was important to calculate what effect addition of this sludge would have on the metals content of the bottom ash and fly ash via simple material balance, and could also be used to determine if the ash analyses were reasonable. Table 5-1 shows the heavy metal and chloride content of the sewage sludges coincinerated during Phase I and Phase II.

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[2] Test Methods for Evaluating Solid Waste, USEPA, SW-486. Method 6010 (As, Ba, Cd, Cr, Pb, Se, Ag) and Method 7471 (Hg).

[3] Standard Methods for the Examination of Water and Wastewater, 17th Edition, 1989, Method 4500B (chlorides) and Test Method for Evaluating Solid Waste, USEPA, SW-846. Method 9038 (sulfates).

Table 5-1
Sewage Sludge Analysis for Heavy Metals and Chlorides (1)

Parameter		Detection Limit	Method Reference	Run 16 A,B,C	Run 17 A,B	Run 17C	Phase II Raw Sludge 1	Phase II Raw Sludge 2
Sludge Solids	wt %			15.5	14.0	16.9	22.1	20.7
Arsenic as Ar	ppm	10	6010	BDL (2)	BDL	BDL	11	BDL
Barium as Ba	ppm	25	6010	57	53	65	820	610
Cadmium as Cd	ppm	25	6010	8.4	7.2	12	62	48
Chromium as Cr	ppm	25	6010	33	28	39	430	450
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL	BDL	BDL
Lead as Pb	ppm	5	6010	19	22	28	51	36
Selenium as Se	ppm	10	6010	BDL	BDL	BDL	BDL	BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL	BDL	BDL
Chlorides	ppm		4500B	66	57	66	320	120

1 Test Methods for Evaluating Solid Waste, SW-846, 3rd ed.,1986 and Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989.

2 BDL = Below Detection Limit

3 Raw Sludge represents sludge "as received" from wastewater treatment plant, and prior to water addition required for the sludge pump/atomization nozzle feed system.

6.0 PILOT DEMONSTRATION TEST

6.1 Pilot Facility Operation

The pilot combustor was operated by Riley Stoker personnel, typically one engineer and two technicians. Air Products' role was to plan and manage the test activities for each day, and to participate and supervise in data collection.

The following sections describe the strategies for executing tests included in the four basic test categories.

6.1.1 Baseline

The objective of baseline testing was to establish the conditions for firing MSW alone. The changes due to oxygen-enriched MSW incineration and oxygen-enriched coincineration of MSW and sewage sludge could be compared to this data. It was intented to operate the pilot unit at its mass limit during the baseline test phase. At the mass limit, additional solid waste feed to the combustor would result in an unacceptable fraction of unburned material leaving the grate. The mass limit is correlated to the carbon content of the bottom ash. In most commercial installations the carbon content of the bottom ash, by permit, cannot exceed 5 wt%.

For each baseline test, the control point for the furnace was specified as 10% excess oxygen in the flue gas on a dry basis. This correlates to approximately 8.5% oxygen in the flue gas on a wet basis. The split between underfire and overfire combustion air was set at approximately 70 and 30%, respectively. In baseline runs, the limiting factor to the MSW feed rate was not the unburned carbon in the bottom ash, but instead the capacity of the induced draft (I.D.) fan. The I.D. fan maintains the negative draft in the combustion chamber. In operating the unit for the baseline runs, the MSW feed rate controlled by the ram feeder speed, and the total combustion air flow were increased until steady-state conditions averaged 10% excess oxygen in the flue gas and while the unit was still able to maintain a fraction of an inch of negative pressure. The I.D. fan operated at 100% capacity.

6.1.2 Oxygen-Enriched MSW Incineration

The primary objective for the oxygen-enriched MSW incineration series of tests was to determine the enhanced rate of MSW combustion due to increasing levels of oxygen in the combustion air. Determining how combustion efficiency was affected by changes in the distribution of oxygen to the underfire and overfire combustion air was a secondary objective of these tests.

Because the operation of the pilot unit was limited by the I.D. fan, it was impossible to use the mass limit of the grate as a criteria to establishing the appropriate MSW feed rate for increasing levels of oxygen enrichment. Instead, the operation of the unit was controlled from a base point neither mass limited nor fan limited. Flue gas excess oxygen was maintained at 10%, on a dry basis.

The control point selected for these runs was the MSW fire line. The MSW fire line could be seen through several observation doors on the side and rear walls of the combustion chamber, and is visually the point on the grate where the flames end. To use the fire line as a control point, the position of the fire line was established without oxygen-enriched air during a baseline run. The MSW feed rate for this baseline run, however, was chosen as the point where the I.D. fan would run at less than full capacity. For increasing levels of oxygen enrichment in the underfire air, the MSW feed rate was increased via the ram feeder speed until the fire line was restored to its baseline position. Operating the pilot unit in this fashion allowed successful measurement of the enhanced combustion rate of the solid waste due to oxygen. The increase in the combustion rate was also seen by the initial displacement of the fire line towards the drying zone after oxygen was introduced.

6.1.3 Oxygen-Enriched Coincineration

In general, the coincineration tests were executed as were the baseline tests: flue gas oxygen was maintained at 10% oxygen (dry basis) and the MSW feed rate was limited to the point where the I.D. fan operated at 100% capacity. The coincineration tests were executed with the two sludge feed systems described in Section 3.2. The only operating change necessary with the addition of sewage sludge and oxygen was to decrease the combustion air flow rate to attempt to maintain 10% excess oxygen in the flue gas. Oxygen was introduced to the system through the sludge atomization nozzle and the underfire and/or overfire air at a rate pre-determined by heat and material balance calculations for the ratio of dry sludge to MSW being coincinerated. The level of oxygen enrichment in the combustion and burnout zones of the underfire air was measured with a field mounted oxygen analyzer.

Referring to Table 2-3, it can be seen that the first coincineration tests were executed during weeks 3 and 5 of Phase I. The tests during week 3 were performed with the sludge pump/sludge extrusion plate feed system. Week 3 was spent troubleshooting the sludge feed system in an attempt to reach a set of conditions where the sewage sludge would completely burn. Data were accumulated in support of test runs during this week, however, the unburned sludge in the bottom ash residue made it apparent that these runs did not successfully demonstrate the coincineration technology. The innovative sludge atomization nozzle was implemented for week 5 of Phase I and for all of Phase II coincineration runs. It was found that dispersing the sludge into fine particles was critical to obtaining complete sludge combustion.

6.1.4 Coincineration Without Oxygen Enrichment

The objectives of the coincineration tests without oxygen enrichment in Phase II were to determine the limits of coincinerating sludge via the atomization nozzle without oxygen, and to collect adequate data so that the differences in coincineration with and without oxygen could be evaluated.

Coincinerating MSW and sludge in the pilot unit required first establishing baseline operation with MSW and then introducing sewage sludge at the desired feed rate. Controlling the furnace was based on adjusting the combustion air flow until the flue gas excess oxygen was maintained close to 10%. Because the operation of the pilot unit was limited by the I.D. fan, it was impossible to maintain flue gas oxygen at the desired level. For the two successful runs in Phase II, 22B and 26B, flue gas excess oxygen on a dry basis was only 7.3 and 8%, respectively.

6.2 Problems Encountered During Test Execution

Unexpected mechanical failures in the pilot combustor and necessary modifications to the sewage sludge feed system, all played some part in reducing the efficiency of the pilot demonstration test. Phase II, consequently, focused on completing the battery of coincineration runs that were not addressed in Phase I. Below is a description of the most significant problems encountered in the operation of the pilot unit.

Waste Feed System - The waste burned throughout the test program was characterized as a shredded waste with 50 to 60% ferrous removal. This waste was selected because it more closely resembled a mass-burn waste than a true refuse-derived fuel, but should have been pre-processed enough to avoid potential plugging problems in the pilot combustor feed chute. In actuality, the waste had a significant fraction of large-sized ferrous and non-ferrous materials.

MSW was stored on site in a trailer and fed to the MSW feed chute, in batches, via a conveyor. The speed setting of the ram feeder determined the constant rate at which the waste would be pushed onto the combustion grate. Because there was no mechanical damper in the feed chute to maintain a seal between the negative pressure in the combustion chamber and the atmosphere, it was necessary for the operators to maintain some level of waste in the feed chute. In cases where the waste appeared wet, maintaining this level in the chute only further compacted the waste, hindering the flow through the chute and onto the grate.

Unfortunately, the size and design of the MSW feed chute and the waste make-up itself were related to several operational problems with the unit during at least the first two weeks of Phase I testing. Frequently, MSW would bridge over the ram feeder preventing a constant flow of waste to the grate. This problem could only be alleviated by an operator manually poking at the waste until the bridge was broken. The bridge was typically caused by a large-sized piece of material or by moist trash as described above. The waste feed problems affected the overall operation of the unit. An interruption in waste feed caused a quick drop in combustion temperature and a rise in CO production. An adjustment in the stroking length of the ram feeder alleviated some of the problems in the feed chute, but trash moisture and size still had a noticeable effect on plugging throughout Phase I and Phase II of the test program.

<u>Pilot Combustor Mechanical Failures</u> - Several mechanical failures in the pilot combustor caused the unit to be shut down for repairs for a minimum of five days of Phase I after operation on those days had already commenced. The most significant failures were:

- Two broken reciprocating grate rods.
- Corrosion of the flue gas sampling probe and sampling line.
- Faulty valves on the pulse-jet baghouse.

The undetected leak in the flue gas sampling line that ultimately led to its failure is also the reason that four baseline runs completed during the first week of testing (3A, 3B, 4A and 4B) were eliminated from the data analysis

<u>Sludge Feed System Replacement</u> - As described in Section 3.2, it was necessary to replace the sludge pump/ sludge extrusion plate feed system with the sludge pump/sludge atomization nozzle feed system in order to successfully coincinerate MSW and sewage sludge. The two problems that plagued the initial sludge feed system design were:

- Solid particles in the sludge would plug the extrusion plate holes preventing flow to the furnace.

- The size of the extruded sludge cake was too large to completely combust on the grate.

The latter problem was detected by visually inspecting the bottom ash and identifying moist and unburned masses of sludge. The odor of unburned sludge could also be detected.

Week 3 (Phase I) of the demonstration test focused on making adjustments to this sludge feed system before concluding that it would need to be replaced by an atomization nozzle that could significantly reduce the sludge particle size. Some of the changes made during Week 3 were:

- Decrease the diameter of the extrusion plate holes from 1/2" to 1/8" to increase the evaporative surface area of the extruded sludge cake.

- Add oxygen to the burnout zone, as well as the combustion zone, to increase the area of the grate where sludge may potentially combust.

- Decrease the feed rate of the sewage sludge since the extruded sludge had the tendency to "pile-up" on the grate. The "piling-up" of sludge on the grate was caused by the relatively fast sludge feed rate compared to the relatively slow movement of the reciprocating grates.

Sludge Atomization Nozzle Erosion - After replacing the sludge extrusion plates with the sludge atomization nozzle in Phase I, three successful runs were made before mechanical failure of the sludge atomization nozzle occurred. This failure was first identified by visually observing that complete atomization of the sludge was not occurring. Instead, a fraction of the sludge feed was falling directly on the combustion/burnout grates in larger sized particles that would not combust.

In the months following Phase I of the pilot test, the nozzle manufacturer analyzed the nozzle tip and discovered that it had eroded from the grit contained in the sewage sludge. For Phase II, the design of the sludge atomization nozzle was modified to reduce the likelihood of erosion. Inspection of the modified sludge nozzle following the Phase II tests showed no sign of erosion.

7.0 DISCUSSION OF PILOT TEST RESULTS

Appendix D-1 contains the operating conditions for all of the runs completed during Phase I and Phase II of the pilot demonstration test program. The tables are divided among Baseline Tests, Oxygen-Enriched MSW Incineration, Oxygen-Enriched Coincineration (sludge extrusion plate feed system), Oxygen-Enriched Coincineration (sludge atomization nozzle feed system), and Coincineration of MSW and Sewage Sludge without Oxygen Enrichment. Each table lists the "successful" and "unsuccessful" runs and defines an "unsuccessful" run. Hereafter, the discussion of results will refer only to the 14 successful runs of Phase I and the 13 successful runs of Phase II. Coincineration refers only to those runs executed when the sludge atomization nozzle was in place, since complete sludge combustion was not achieved with the sludge pump/ sludge extrusion plate feed system.

7.1 Presentation of Pilot Test Results

Table 7-1 summarizes the average operating conditions for the Phase I and Phase II tests. Baseline runs from Phase I and Phase II are listed separately, and not averaged together, since they represent baseline operation for two different MSW feed streams. Table 7-1 further divides oxygen-enriched MSW incineration tests into several levels of enrichment, and oxygen-enriched coincineration tests into several levels of dry sludge to MSW.

Table 7-1 shows that the pilot unit was operated to maintain an average excess oxygen in the flue gas between 8.3 and 9.7% on a wet basis during Phase I, and between 6.3 and 8.5% on a wet basis during Phase II. On a dry basis, the range of flue gas excess oxygen was 9.7 to 11.6% in Phase I and 8.0 to 11.3% in Phase II. During Phase II the pilot unit operated at a lower flue gas excess oxygen (wet basis) because the I.D. fan limited the combustion air flow during coincineration runs without oxygen enrichment, and also because of the increase in flue gas moisture due to sludge.

The average unburned carbon content of the bottom ash and fly ash is also given in Table 7-1. The average carbon content in the bottom ash ranged from < 0.1 to 0.95 wt% and in the fly ash from 0.7 to 3.7 wt%. The carbon content of these ashes confirmed that the pilot unit was operated to achieve adequate burnout. The carbon content of the ash for pilot unit operation was relatively low when compared to commercial W-t-E plants.

The line item, "Tramp Air for Mass Closure," is that amount of air needed to establish material balance closure. "Tramp air" is a term commonly used in the W-t-E industry to describe the air that leaks into the furnace and heat recovery system. On-line tramp air measurements during the pilot test program ranged from 230 pounds per hour (pph) to 1060 pph, and averaged approximately 840 pph. The average tramp air calculated from the material balances for the above test categories ranged from 366 to 933 pph, and averaged 633 pph.

The grate temperature was measured via a thermocouple located on the underside of the combustion grate. A sketch showing the location of the combustion grate thermocouple is shown in Figure 7-1. The objective of measuring the grate temperature was to show that although a rise in the grate temperature due to oxygen enrichment was expected, the temperature rise was not excessive for typical materials of construction for mass-burn unit combustion grates. Average grate temperatures ranged from 437°F (Phase I Baseline) to 759°F(Oxygen-Enriched MSW Incineration). The average grate temperature during the Phase II coincineration runs was 505°F.

A better analysis of the pilot test coincineration data can be made by normalizing the data to a constant flue gas excess oxygen. Knowing the composition of the flue gas for each run, the test data was corrected by adjusting the combustion air flow until 8.5% excess oxygen was achieved. The effect of increasing or decreasing the combustion air, and therefore the flue gas flow, on first pass furnace temperature was also estimated. The

Table 7-1
Pilot Test Operating Conditions Summary

Phase I		Baseline	O2 Enriched MSW Incineration				O2 Enriched Coincineration
O2 Enrichment Zone (1)			Comb	Comb	Comb / OFA	OFA	Comb
Oxygen, mole %			23.7 - 24.3	26.6 - 27.1	27.0 / 25.4	25.1	24.9 - 26.5
MSW	pph	539 - 668	564 - 677	633 - 720	711	586	525 - 582
Sludge	pph	0	0	0	0	0	130 - 170
Oxygen	pph	0	83	166	216	50	100 - 133
dry Sludge/MSW	wt %						3.8 - 4.5
Oxygen/dry Sludge	wt %						4.2 - 6.6
O2, dry	vol %	9.7	10.6	11.2	11.6	10.2	10.5
O2, wet	vol %	8.3	9.2	9.6	9.7	8.6	8.6
Flue Gas Moisture	vol %	14.2	13.4	14.5	16.6	15.3	18.8
Ash Content	wt %	18.0	18.5	18.1	17.4	19.2	14.9
Bottom Ash Carbon	wt %	0.53	0.95	0.44	0.83	0.35	0.64
Fly Ash Carbon	wt %	2.51	2.08	1.94	1.98	3.70	2.15
First Pass Temperature	F	1531	1646	1662	1744	1553	1515
Flame Temp (Comb Zone)	F	2144	2215	2292	2380	2037	2192
Comb Grate Temp	F	437	606	741	759	438	612
Tramp Air for Mass Closure	pph	514	588	408	704	366	371
Number of Runs		4	2	3	1	1	3
Run No.		7A, 8A, 13A, 14A	7B, 13B	7C, 13C, 14B	14C	9A	16A, 16B, 17B

Table 7-1 (Continued)
Pilot Test Operating Conditions Summary

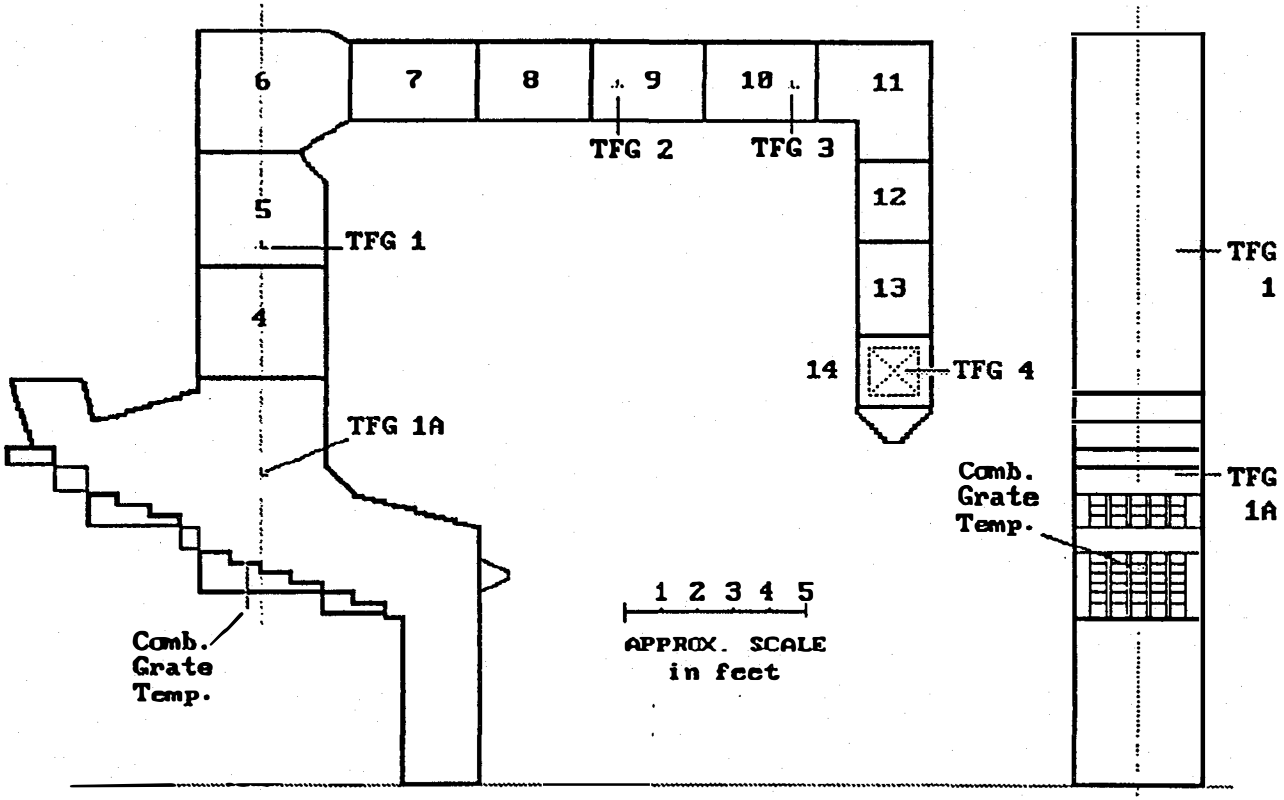
Phase II		Baseline	Coincineration without O2	O2 Enriched Coincineration			
O2 Enrichment Zone (1)				OFA	OFA	OFA	Sludge Gun
Oxygen, mole % (2)				36.3	34.1 - 43.7	41.2	
MSW	pph	575 - 649	552 - 616	610	583 - 697	591	750 - 752
Sludge	pph	0	235 - 370	235	370	490	370
Oxygen	pph	0	0	210	171 - 302	272	272 - 328
dry Sludge/MSW	wt %		5.1 - 11.3	5.8	8.2 - 9.5	11.0	6.6 - 7.2
Oxygen/dry Sludge	wt %			5.9	3.1 - 5.4	4.2	5.0 - 6.6
O2, dry	vol %	9.9	8.0	10.0	8.9	10.9	11.3
O2, wet	vol %	8.5	6.3	8.0	6.6	8.0	8.3
Flue Gas Moisture	vol %	14.5	20.8	20.5	25.9	27.0	26.5
Ash Content	wt %	18.6	14.4	16.3	12.6	12.8	16.9
Bottom Ash Carbon	wt %	< 0.3	0.3	< 0.1	0.3	0.2	< 0.3
Fly Ash Carbon	wt %	< 1.1	1.2	1.0	1.0	0.8	0.7
First Pass Temperature	F	1608	1607	1683	1750	1671	1662
Flame Temp (Comb Zone)	F	2079	2072	2150	1996	1955	2220
Comb Grate Temp	F	377	285	288	513	459	626
Tramp Air for Mass Closure	pph	794	747	933	762	569	845
Number of Runs		4	2	1	3	1	2
Run No.		20,22A,23A,24A	22B, 26B	22C	23B, 23C, 24B	24C	25B, 25C

Notes -

1 Comb = Combustion Zone of Underfire Air, OFA = Overfire Air, Sludge Gun = Sludge Atomization Nozzle

2 Sludge gun atomization air is not included in OFA flow

Figure 7-1: Combustion Grate Schematic - Grate Thermocouple Location



assumption was made that the change in the first pass temperature would be equivalent to the change in the combustion temperature resulting from the change in the flue gas flow. The normalized pilot plant data are presented in Table 7-2 and will be discussed in Sections 7.1.2 and 7.1.3.

7.1.1 Oxygen-Enriched MSW Incineration

Prior to the pilot test, there were no data available documenting the effect of oxygen enrichment on the combustion of a solid waste fuel like a mass-burn MSW. Correlations have been prepared for oxygen-enriched coal combustion, however, it was important in the development of this technology to generate data showing the relationship between MSW combustion rate and the level of oxygen enrichment.

Figure 7-2 summarizes the effect of oxygen enrichment on the MSW combustion rate based on results from Runs 7A-C, 13A-C, and 14A-C. Compared to the baseline MSW feed rates measured during these three test runs, an average of 24% oxygen in the combustion zone underfire air yielded approximately a 9% increase in the MSW throughput, whereas an average of 26% oxygen in the same zone yielded approximately a 20% increase in the MSW throughput. These results indicate that oxygen enrichment can significantly increase the mass limit of an existing MSW incinerator.

The effect of oxygen enrichment on flue gas emissions is discussed separately in Section 7.2.

7.1.2 Oxygen Enriched Coincineration of MSW and Sewage Sludge

Between Phase I and Phase II, ten runs were successfully executed to demonstrate the oxygen-enriched coincineration process. In two runs, 25B and 25C, oxygen was used as the atomization gas in the sludge nozzle. In the other eight runs, oxygen was used to enrich either overfire air or the combustion zone of the underfire air, allowing air to be used as the atomization gas. The motivation for introducing oxygen through the sludge nozzle was to improve the efficiency of sludge combustion as it was fed to the furnace. However, the oxygen requirement for sludge atomization was greater than that needed for the combustion process. In runs 25B and 25C, oxygen was fed to the furnace in amounts greater than five pounds oxygen per pound of dry sludge.

The ratio of dry sludge to MSW coincinerated during the pilot demonstration program ranged from 3.8 to 11%, without affecting the carbon content of the ash. As indicated in Table 7-1, the additional moisture entering the furnace from the addition of sludge increased the flue gas moisture from a baseline average of 14.4 to 27%. Other important observations made during the coincineration runs are listed below:

- The overall operation and control of the furnace was unaffected by the introduction of sewage sludge and oxygen.
- Because of the particle size of the atomized sludge, sludge could not be seen as it was introduced into the furnace.
- It is believed that the sludge particles burned in suspension at the point where they were introduced since there was no visual evidence of sludge quenching flames on the burning bed of refuse.
- Oxygen enrichment of the underfire air increased the brightness of the bed flame.

Figure 7-3 is a graphical representation of the Phase I and Phase II coincineration data. For comparison, the theoretical oxygen requirement of the process based on 7.5, 8.5, and 9.5% excess oxygen (wet basis) are also shown.

Table 7-2: Normalized Pilot Plant Data

Run No.	Flue Gas O2 (%)	O2/Dry Sludge (lb/lb)	Dry Sludge/MSW (%)	Flue Gas (lbmol/hr)	1st Pass Temp (F)	Flue Gas @ 8.5% O2 (lbmol/hr)	1st Pass Temp @ 8.5% O2 (F)
Baseline:							
7A	8.6			170	1513	168.5	1531
8A	7.4			180	1535	196	1368
13A	8.3			153	1561	155.5	1528
14A	9.0			168	1514	161	1603
20	8.6			169	1601	167.5	1619
22A	7.7			171	1560	181.6	1441
23A	8.3			181	1669	184	1636
24A	8.2			171	1602	175	1555
Average				**170**	**1,569**	**174**	**1,535**
Coincineration:							
16C	8.1		3.3	153	1494	158	1429
22B	5.8		5.1	176	1605	214	1243
26B	6.8		11.3	178	1608	202.2	1364
Average				**169**	**1,569**	**191**	**1,345**
O2 Enriched Coincineration:							
16A	8.3	4.3	4.0	162	1480	164.5	1449
16B	8.7	6.6	3.8	154	1574	151.9	1602
17B	8.7	4.2	4.5	158	1491	155.5	1524
22C	8.0	5.9	5.8	176	1683	183	1605
23B	6.2	4.3	8.2	182	1759	215.5	1442
23C	5.6	3.1	8.7	173	1767	209	1416
24B	8.1	5.4	9.5	171	1725	176.5	1661
24C	8.0	4.2	11.0	182	1671	189.3	1592
25B	7.6	5.0	7.2	183	1684	196.2	1547
25C	9.0	6.6	6.6	178	1640	171	1724
Average				**172**	**1,647**	**181**	**1,556**

Note - Combustion air has been adjusted in each run to normalize flue gas excess O2 to 8.5% (wet).

Figure 7-2: Effect of Oxygen Enrichment on Plant MSW Capacity

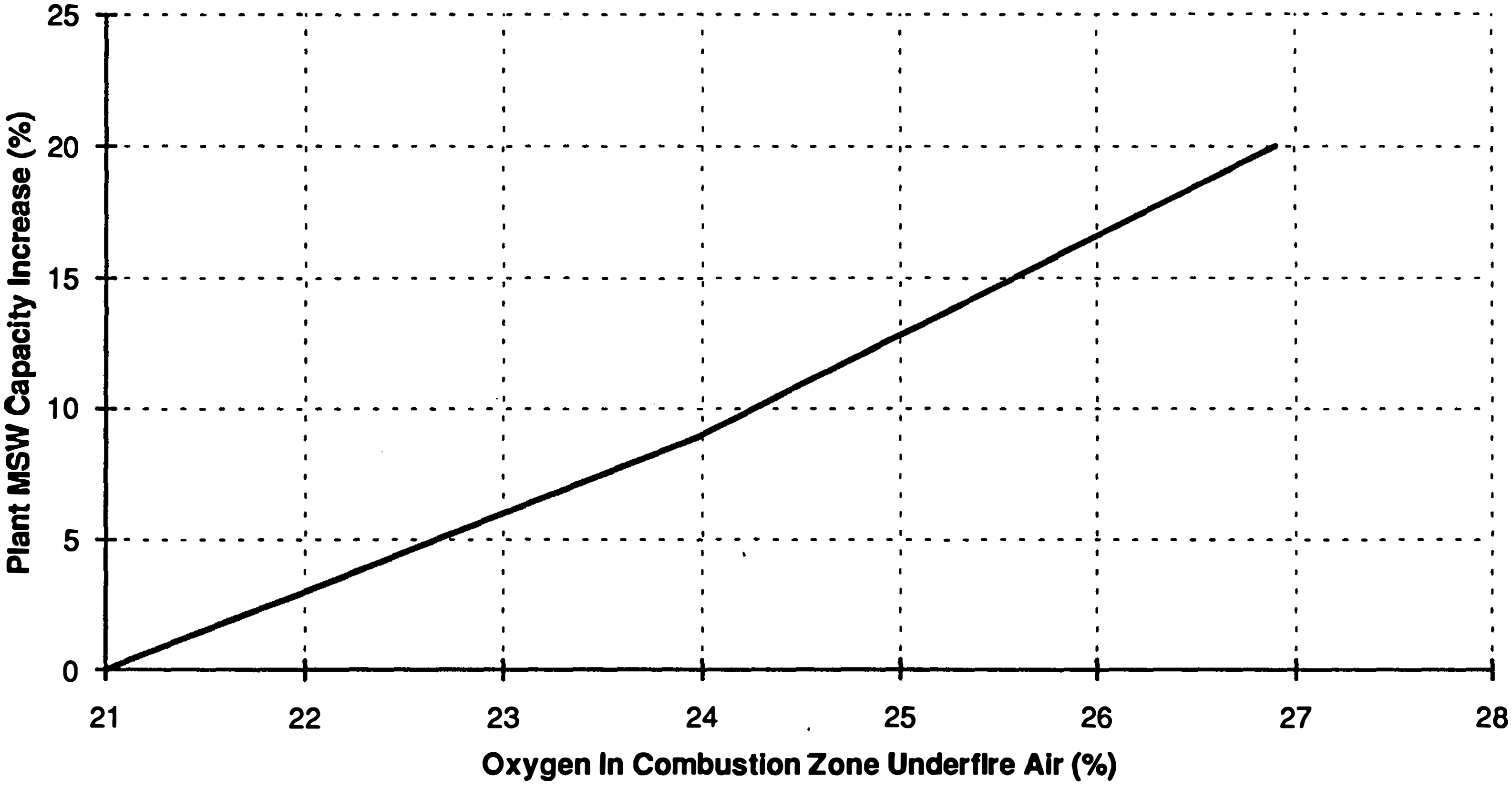
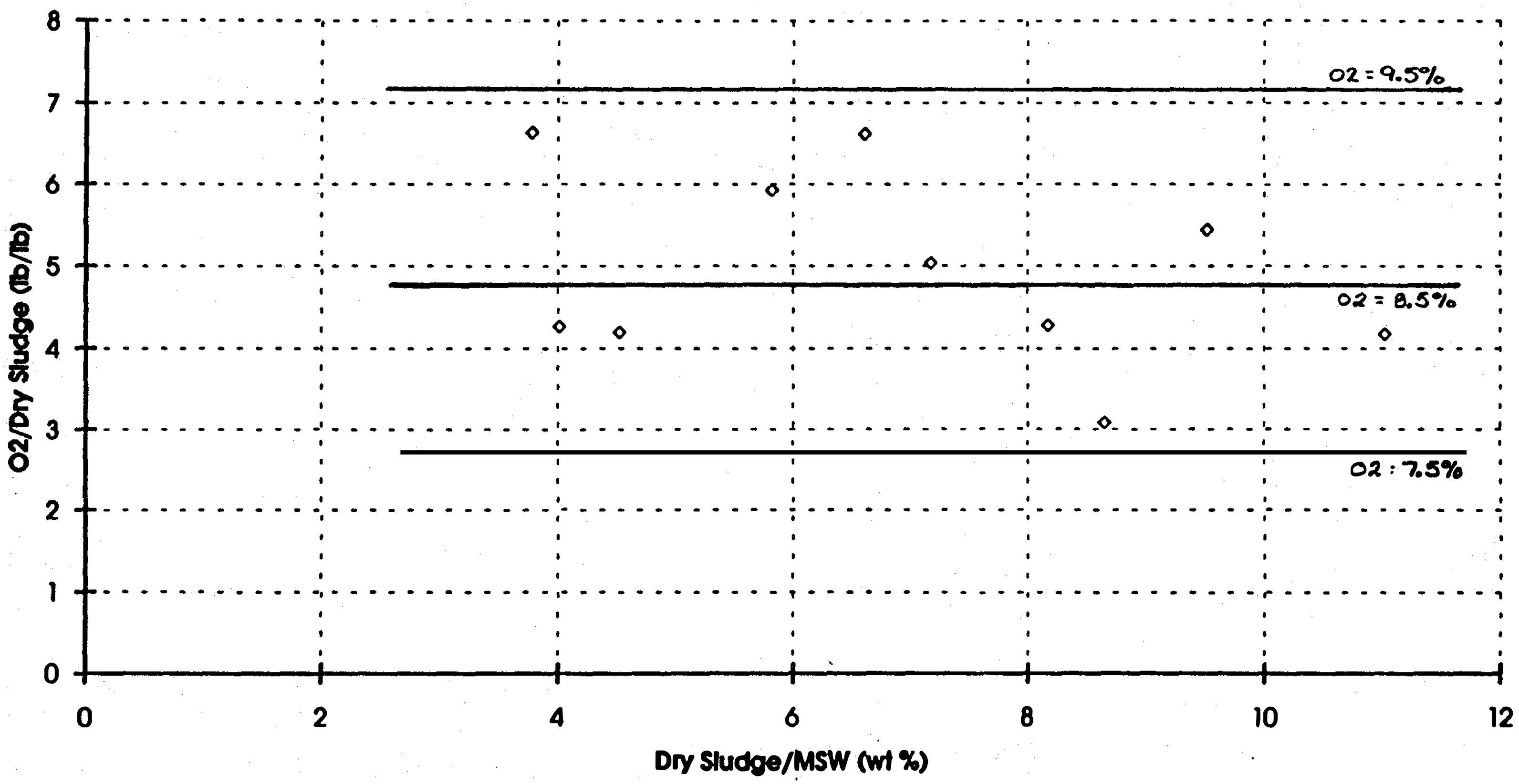


Figure 7-3: Coincineration Data for Phase I and Phase II



More meaningful conclusions from the coincineration data can be drawn by examining the normalized data of Table 7-2. First, coincinerating MSW and sewage sludge with oxygen-enriched air increased the baseline flue gas flow by less than 5%. The premise of the process was to show that oxygen and sludge addition would have little or no effect on baseline operating conditions.

Figure 7-4 shows the adjusted first pass temperature as a function of the oxygen to dry sludge ratio. To maintain the baseline operating conditions—a first pass temperature of 1535°F—Figure 7-4 shows the appropriate level of oxygen usage to be in the range of 3.5 to 5.5 pounds oxygen per pound of dry sludge. Oxygen usage below this range will cause the combustion temperature to drop below 1535°F, and oxygen usage above this range will cause the combustion temperature to rise above 1535°F.

7.1.3 Coincineration of MSW and Sewage Sludge Without Oxygen Enrichment

In three runs, 16C, 22B, and 26B, MSW and sewage sludge were successfully coincinerated without oxygen enrichment. The ratios of dry sludge to MSW that were coincinerated ranged from 3.3 to 11.3%, equivalent to that demonstrated with oxygen enrichment. The innovative sludge atomization nozzle made it possible to exceed the conventional coincineration limits of 2 to 3 wt% dry sludge/MSW.

To evaluate these coincineration runs, it was especially critical to analyze the normalized data. As shown in Table 7-2, the normalized data yields an average adjusted first pass temperature of 1345°F, and an adjusted flue gas flow of 191 lbmol/hr. Compared to baseline, this represents a 200°F decrease in combustion temperature, and a 10% increase in flow to the air pollution control equipment. The reduction in furnace temperature would negatively effect combustion efficiency and flue gas emissions. At some level of coincineration, the combustion temperature would decrease to the point where combustion could not be sustained.

The pilot test results demonstrated that coincineration without oxygen enrichment is achievable, but not without adversely affecting combustion temperature and flue gas flow rate.

7.2 Flue Gas Emissions Summary

In Sections 7.2.1 through 7.2.5, the effect of oxygen enrichment and/or coincineration with sewage sludge on the flue gas emissions CO, NO_x, SO_2, HCl, and THC will be discussed. A summary of the average flue gas emissions for the pilot test runs is given in Table 7-3. All data has been corrected to 7% flue gas oxygen. A complete set of data for all runs is given in Appendix D-2.

7.2.1 Carbon Monoxide (CO)

Figure 7-5 shows CO emissions as a function of first pass temperature for the Phase 1 and Phase II tests. The data correlate well, and suggest that the dominant variable affecting flue gas CO was the furnace combustion temperature. Higher furnace temperatures effectively reduced CO emissions by improving combustion efficiency. The effect of oxygen and/or sewage sludge on the combustion efficiency, if any, appears to be secondary to combustion temperature.

7.2.2 Nitrogen Oxides (NO_x)

Figure 7-6 shows the correlation of Phase I and Phase II NO_x emissions to flue gas excess oxygen. In general, the data showed that flue gas NO_x increased with increasing flue gas excess oxygen, suggesting that NO_x formation may be influenced by the availability of oxygen in the flue gas. Figure 7-6 also shows that straight enrichment runs and oxygen-enriched coincineration runs averaged higher NO_x emissions than their respective baseline runs, even at similar levels of flue gas excess oxygen. This increase in flue gas NO_x cannot be solely

Figure 7-4: Oxygen Usage for MSW and Sewage Sludge Coincineration

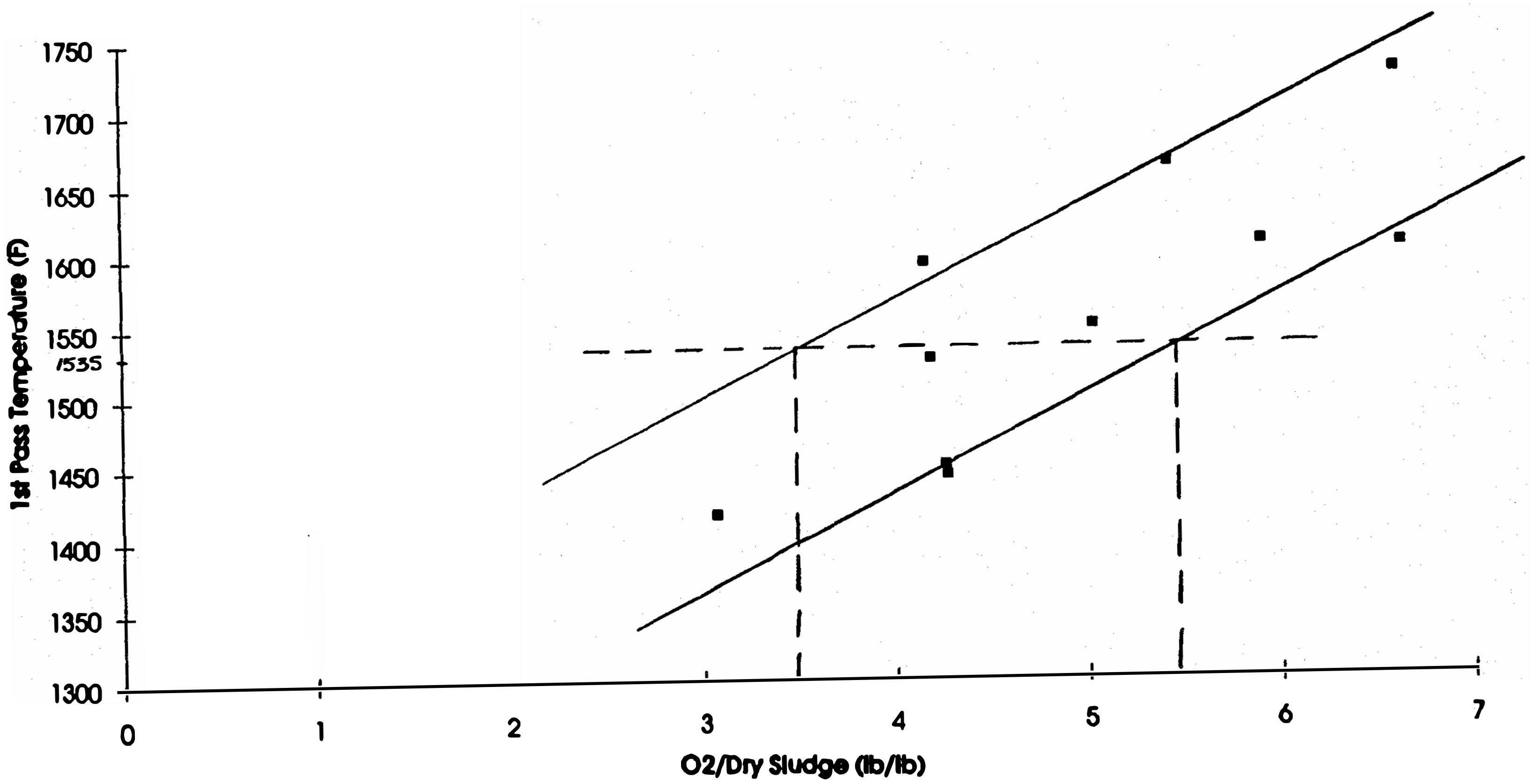


Table 7-3
Pilot Test Flue Gas Emissions Summary

Phase I		Baseline	O2 Enriched MSW Incineration				O2 Enriched Coincineration
O2 Enrichment Zone (1)			Comb	Comb	Comb/OFA	OFA	Comb
Oxygen, mole %			23.7 - 24.3	26.6 - 27.1	27.0 / 25.4	25.1	24.9 - 26.5
O2, average	%	9.7	10.6	11.2	11.6	10.2	10.5
CO2, average	%	9.8	10.3	11.0	11.3	10.0	10.7
CO, average @ 7% O2 (2)	ppm	152	101	111	103	104	235
NOx, average @ 7% O2	ppm	251	285	328	334	262	246
SO2, average @ 7% O2	ppm	157	179	232	308	109	202
HC, average @ 7% O2	ppm	4.7	3.0	7.7	3.7	0.6	15.8
HCl, average @ 7% O2	ppm	304	305	336	438	383	333
Number of Runs		4	2	3	1	1	3
Run No.		7A, 8A, 13A, 14A	7B, 13B	7C, 13C, 14B	14C	9A	16A, 16B, 17B
Phase II		**Baseline**	**Coincineration without O2**	**O2 Enriched Coincineration**			
O2 Enrichment Zone (1)				OFA	Sludge Gun		
Oxygen, mole %				34.1 - 43.7			
O2, average	%	9.6	8.0	9.5	11.3		
CO2, average	%	9.7	11.2	13.4	13.1		
CO, average @ 7% O2 (2)	ppm	104	146	83	121		
NOx, average @ 7% O2	ppm	211	162	283	355		
SO2, average @ 7% O2	ppm	103	137	201	145		
HC, average @ 7% O2	ppm	3.1	10.3	4.8	4.1		
Number of Runs		4	2	5	2		
Run No.		20,22A,23A,24A	22B, 26B	22C, 23-24 B/C	25B, 25C		

Notes -

1 Comb = Combustion Zone of Underfire Air, OFA = Overfire Air, Sludge Gun = Sludge Atomization Nozzle

2 CO data corrected, > 800 ppm CO (measured) was deleted due to furnace excursions.

Figure 7-5: Carbon Monoxide (CO) Emissions

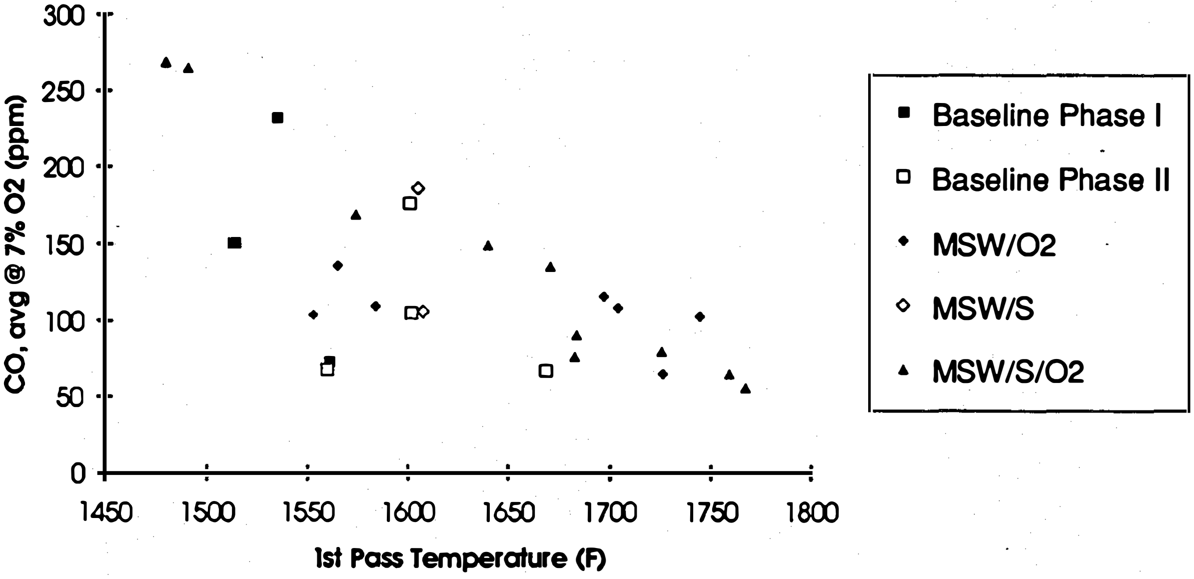
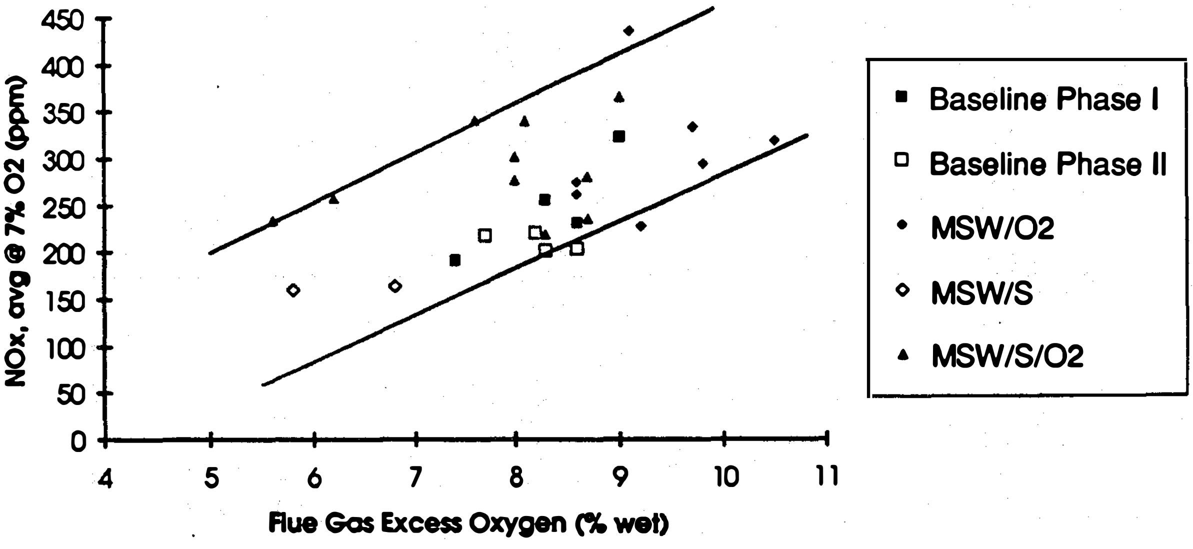


Figure 7-6: Nitrogen Oxide (NOx) Emissions as a Function of Excess Oxygen



attributed to thermal NO_X formation, as one might have expected[4]. Figure 7-7 shows only a weak correlation between flue gas NO_X and temperature. Instead, one can conclude that it is oxygen enrichment, coupled with the additional molecular nitrogen contained in the sludge that is responsible for the increase in flue gas NO_X.

Figure 7-8 further correlates the oxygen to dry sludge ratio with flue gas NO_X for the oxygen-enriched coincineration runs performed during Phase II. Clearly, NO_X emissions increased as the ratio of oxygen to dry sludge increased. Oxygen enrichment, with and without sludge present, seems to be the dominant variable affecting flue gas NO_X emissions.

The relationships shown in Figures 7-6 through 7-8 emphasize the need to optimize the oxygen to dry sludge ratio and the location where oxygen is introduced when coincinerating MSW and sewage sludge, in order to minimize the changes in flue gas NO_X.

7.2.3 Sulfur Dioxide (SO_2)

Similar to the conclusions drawn from the flue gas NO_X data, Figure 7-9 also shows a correlation between flue gas SO_2 and flue gas excess oxygen. With or without the addition of sludge or oxygen, SO_2 emissions increased as the furnace was operated at increasing levels of excess oxygen. Recognizing this, the measured increase in flue gas SO_2 for Phase II coincineration runs cannot be solely related to the sulfur content of the sewage sludge.

Figure 7-10 shows the effect of oxygen enrichment of the combustion zone underfire air based on the straight enrichment runs performed during Phase I. With the exception of a single point, the increase in SO_2 measured during these runs can be correlated to the enrichment level of the combustion air. The pilot test data suggest that oxygen enrichment may improve conversion of sulfur contained in fuel to SO_2. In combustion furnaces today, since the conversion of sulfur in the fuel to SO_2 is believed to be only 60 to 70%, this occurrence is likely. The test results show that for every increase in flue gas SO_2, there is a corresponding decrease in the sulfate content of the bottom ash. In Phase I, bottom ash sulfate decreased from a baseline of 3650 to 1367 ppm with the highest level of straight enrichment. Also in Phase II, baseline bottom ash sulfate decreased from a baseline of 2200 to 1559 ppm with oxygen-enriched coincineration.

During Phase II, two coincineration runs were performed without oxygen-enriched air. Compared to the Phase II baseline SO_2 of 103 ppm, average SO_2 increased to 177 ppm and decreased to 96 ppm when coincinerating 235 and 370 pph of sewage sludge, respectively. It is impossible from the test results to correlate the sulfur content of the sludge with the measured changes in SO_2. It is possible, though, to calculate the impact sludge could have on the flue gas, assuming 60% of the sulfur contained in the sludge was converted to SO_2. Knowing the sulfur content of the sewage sludge used in the demonstration test to be 0.1% (wet basis), the maximum increase in flue gas SO_2 due to 370 pph of sludge would be 30 ppm. The pilot plant test results, however, show greater sensitivity to oxygen enrichment than to the sulfur content of the sludge.

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[4] Thermal NOx is nitrogen oxides formed in high temperature combustion processes by reaction of molecular nitrogen contained in the combustion air with oxygen.

Figure 7-7: Nitrogen Oxide (NOx) Emissions as a Function of Temperature

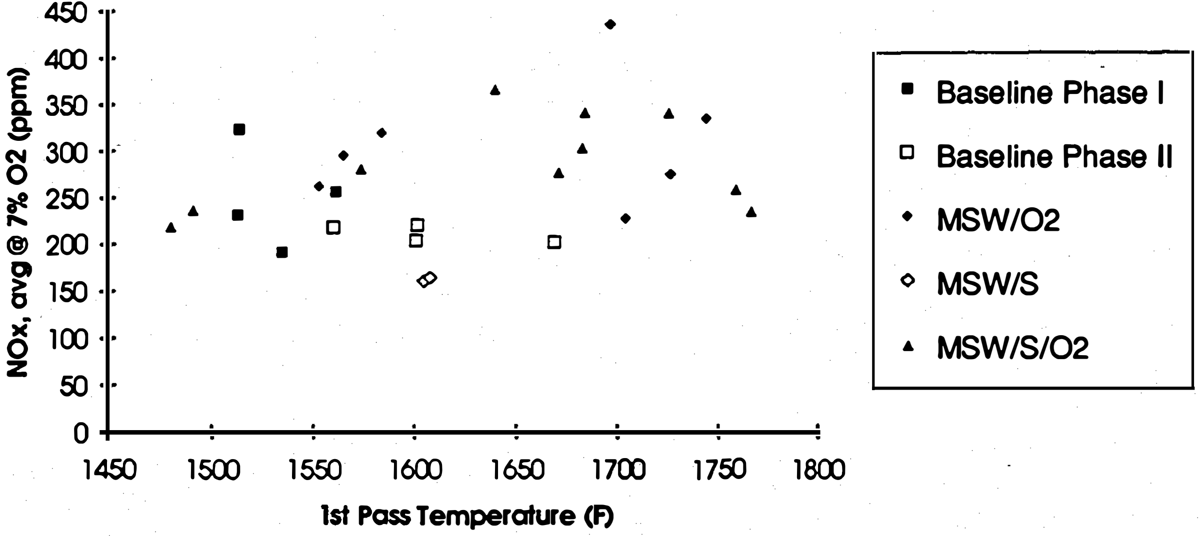


Figure 7-8: NOx Emissions for Oxygen-Enriched Coincineration

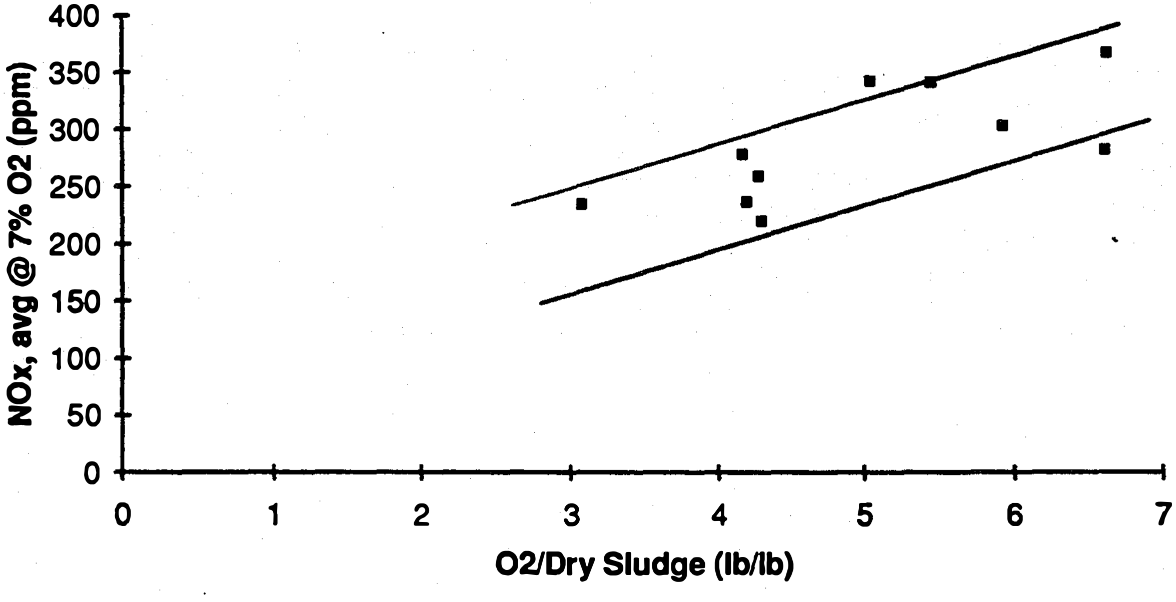


Figure 7-9: Sulfur Dioxide (SO2) Emissions

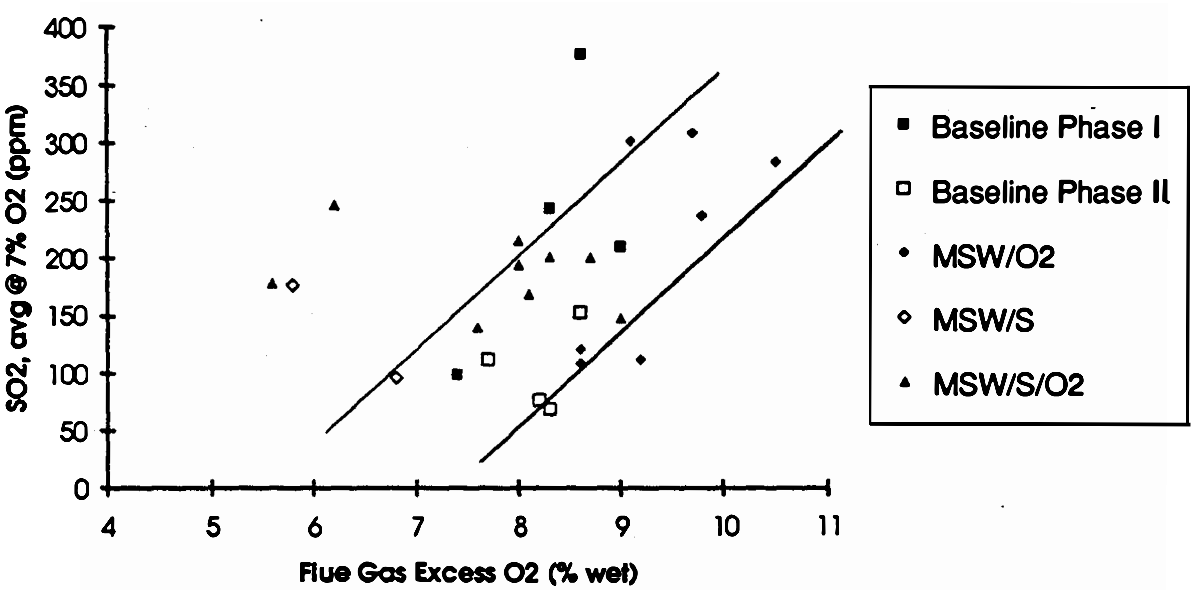
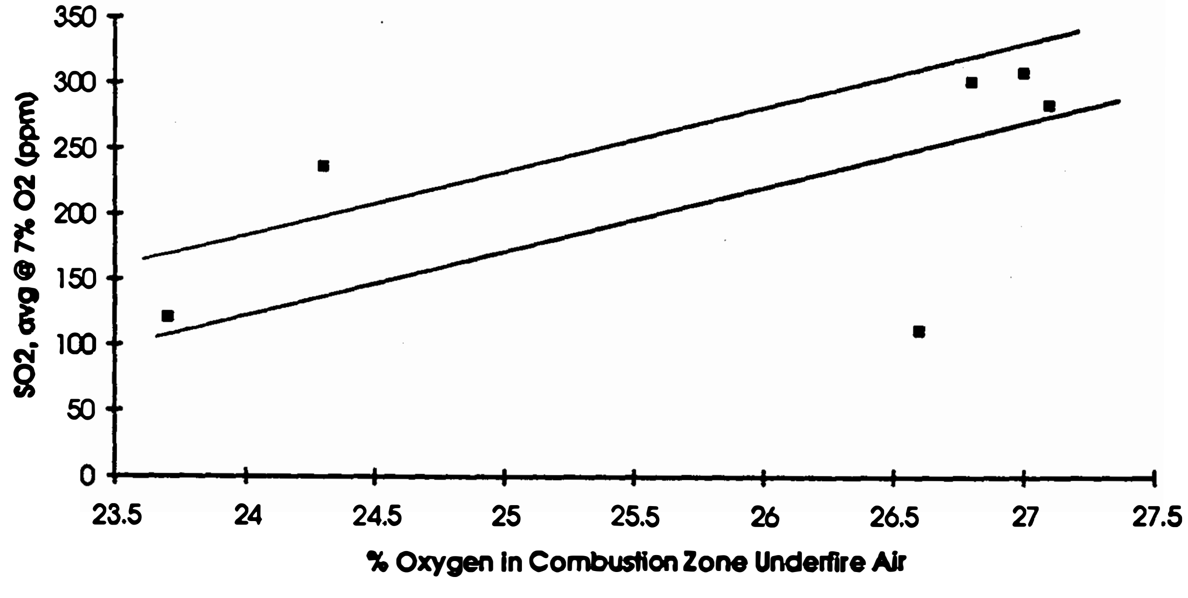


Figure 7-10: Effect of Oxygen Enrichment on Flue Gas SO2



7.2.4 Hydrochloric Acid (HCl)

Flue gas HCl was measured throughout Phase I of the pilot test. During baseline and coincineration runs, untreated flue gas HCl ranged from approximately 250 to 400 ppm. Flue gas HCl peaked during the straight enrichment runs at 438 ppm.

In Figure 7-11, flue gas HCl is plotted against first pass temperature. In general, the data appear scattered with a weak correlation to first pass temperature. Focusing on the straight enrichment runs and identifying the test run numbers, however, it is apparent that runs performed on the same day have similar levels of flue gas HCl. For example, runs 13B and 13C average 202 ppm, while runs 14B and 14C average 403 ppm. These results suggest that the measured changes in flue gas HCl are a function of the variability in the chlorine content of the MSW and/or sewage sludge.

7.2.5 Total Hydrocarbons (THC)

Total hydrocarbons seemed to be the pollutant most affected by upsets in the operation of the furnace. The trend of the hydrocarbon emissions during Run 26B is shown in Figure 7-12 as an example.

As shown in Table 7-3, hydrocarbon emissions increased slightly in Phase II from a baseline of 3.1 ppm to 4.8 and 4.1 ppm while coincinerating with oxygen in the overfire air and the sludge atomization nozzle, respectively. Averaging all straight enrichment runs in Phase I, hydrocarbons decreased from a baseline of 4.7 to 3.8 ppm. The most significant increase in flue gas hydrocarbons to 10.3 ppm was measured for the two coincineration runs without oxygen enrichment, 22B and 26B, in Phase II.

7.3 Bottom Ash and Fly Ash

As described in Section 5-2, bottom ash and fly ash samples were analyzed throughout the pilot demonstration program to evaluate the effect sewage sludge and oxygen would have on the heavy metal, chloride, and sulfate contents of these materials. Table 7-4 presents the results of the ash analyses. A complete set of the ash data for all tests is given in Appendix D-3.

In general, one may conclude from the results found via this pilot test that neither oxygen-enriched MSW incineration or oxygen-enriched coincineration have a significant effect on the heavy metal content of the ash produced by a W-t-E facility. None of the eight RCRA metals measured deviated significantly from the baseline average. The most scatter seen in the data was for lead, where lead both increased and decreased from baseline averages in Phase I and Phase II, respectively. The following explanations can be made:

- The change in lead content of the bottom and fly ash does not appear to be a function of the addition of sewage sludge and/or oxygen.

- The lead content of the ash is more likely a function of ash sampling, or the variability in the lead content of the MSW itself.

Chloride levels in the bottom and fly ash seem virtually unaffected by oxygen and/or sludge addition, in contrast to sulfate levels which dramatically decrease with increasing levels of oxygen enrichment. Figure 7-13 shows the effect of enriching combustion zone underfire air with oxygen on bottom ash sulfate. Baseline bottom ash sulfate decreased from an average of 3650 ppm to an average of 1367 ppm with 26.6 to 27.1% enrichment. In Phase II, baseline bottom ash sulfate also decreased from 2200 to 1559 ppm with oxygen-enriched coincineration while enriching the overfire air. These test results, coupled with the emissions results, indicate that the conversion of chlorine contained in the MSW to HCl was high and unaffected by coincineration. However, conversion of sulfur to SO_2 was improved with oxygen enrichment.

Figure 7-11: Hydrochloric Acid (HCl) Emissions

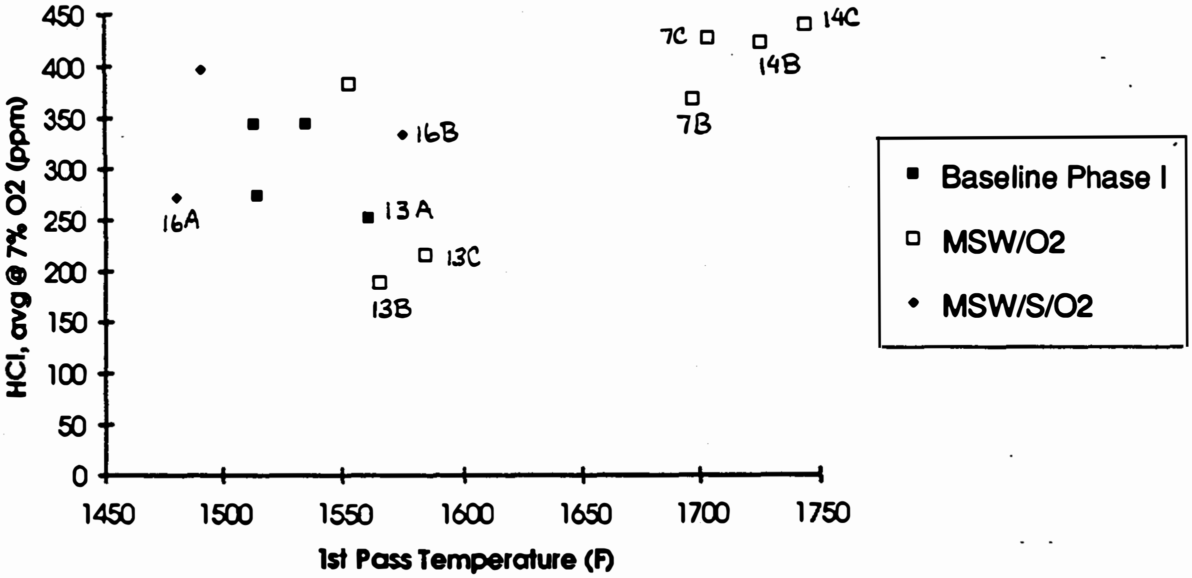


Figure 7-12: Flue Gas Hydrocarbon Emission Trend (Run 26B)

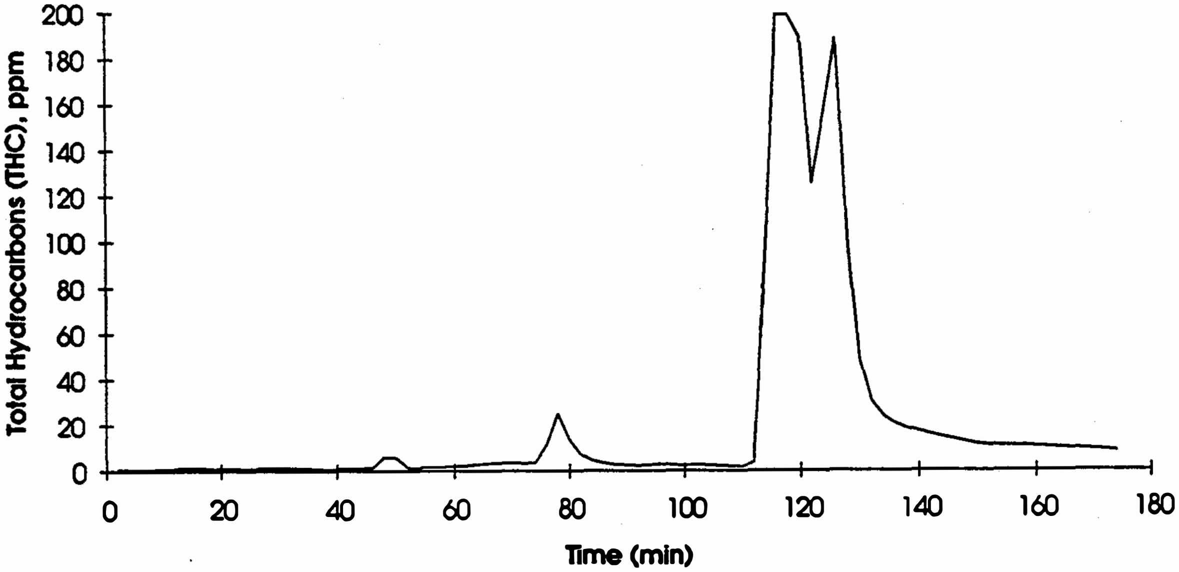


Table 7-4
Bottom Ash / Fly Ash Summary - Phase I/Phase II

Phase I		Detection Limit	Method Reference (1)	Baseline	O2 Enriched MSW Incineration				Oxygen-Enriched Coincineration
O2 Enrichment Zone (2)					Comb	Comb	Comb/OFA	OFA	Comb
Oxygen, mole %					23.7 - 24.3	26.6 - 27.1	27.0 / 25.4	25.1	24.9 - 26.5
Bottom Ash:									
Arsenic as As	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL
Barium as Ba	ppm	25	6010	828	535	783	490	700	710
Cadmium as Cd	ppm	2.5	6010	5.0	3.0	3.5	8.6	6.7	8.5
Chromium as Cr	ppm	2.5	6010	79	49	68	110	86	84
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL	BDL	BDL	BDL
Lead as Pb	ppm	50	6010	520	1,425	860	1,800	280	1,657
Selenium as Se	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL	BDL	BDL	BDL
Chloride (water extractable)	ppm	150	4500B	2,250	2,000	1,257	2,200	410	2,100
Sulfate (water extractable)	ppm	150	9038	3,650	2,225	1,367	1,800	410	1,967
Total Organic Carbon	wt %	0.1		0.53	0.95	0.44	0.83	0.35	0.64
Fly Ash:									
Arsenic as As	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL
Barium as Ba	ppm	25	6010	13	417	395	460	690	495
Cadmium as Cd	ppm	25	6010	1,100	930	1,007	820	1,300	775
Chromium as Cr	ppm	25	6010	195	155	147	130	140	380
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL	BDL	BDL	BDL
Lead as Pb	ppm	50	6010	7,500	12,000	13,333	15,000	24,000	16,000
Selenium as Se	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL	BDL	BDL	BDL
Chloride (water extractable)	ppm	150	4500B	130,000	150,000	170,000	170,000	180,000	107,000
Sulfate (water extractable)	ppm	1500	9038	43,500	34,500	32,383	27,000	36,000	17,500
Total Organic Carbon	wt %	0.1		2.52	2.08	1.94	1.98	3.7	2.13
Number of Runs				4	2	3	1	1	3
Run No.				7A, 8A, 13A, 14A	7B, 13B	7C, 13C, 14B	14C	9A	16A, 16B, 17B

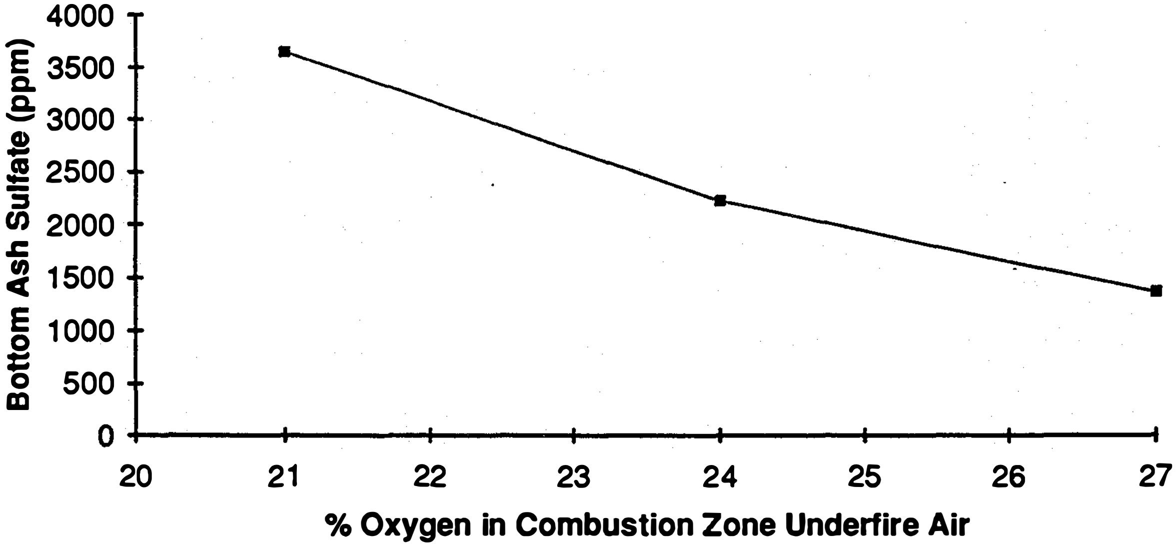
Table 7-4 (Continued)
Bottom Ash / Fly Ash Summary - Phase I/Phase II

Phase II		Detection Limit	Method Reference (1)	Baseline	Coincineration without O2	Oxygen-Enriched Coincineration
O2 Enrichment Zone*						OFA/Sludge Gun
Oxygen, mole %						34.1 - 43.7
Bottom Ash:						
Arsenic as As	ppm	10	6010	BDL	BDL	BDL
Barium as Ba	ppm	25	6010	435	475	447
Cadmium as Cd	ppm	2.5	6010	3.7	3.7	6.2
Chromium as Cr	ppm	2.5	6010	52	53	53
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL
Lead as Pb	ppm	50	6010	1150	470	440
Selenium as Se	ppm	10	6010	BDL	BDL	BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL
Chloride (water extractable)	ppm	150	4500B	1,650	1,785	1,857
Sulfate (water extractable)	ppm	150	9038	2,200	2,400	1,559
Total Organic Carbon	wt %	0.1		< 0.2	0.26	0.31
Fly Ash:						
Arsenic as As	ppm	10	6010	143	125	152
Barium as Ba	ppm	25	6010	263	380	274
Cadmium as Cd	ppm	25	6010	323	205	300
Chromium as Cr	ppm	25	6010	130	119	158
Mercury as Hg	ppm	0.1	7471	0.27	0.38	0.26
Lead as Pb	ppm	50	6010	7,667	6,400	8,120
Selenium as Se	ppm	10	6010	BDL	BDL	BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL
Chloride (water extractable)	ppm	150	4500B	20,833	27,000	25,000
Sulfate (water extractable)	ppm	1500	9038	32,333	25,500	35,600
Total Organic Carbon	wt %	0.1		2.49	1:22	0.89
Number of Runs				3	2	7
Run No.				20, 23A, 24A	22B, 26B	22C, 23 24 25 B/C

1 Test Methods for Evaluating Solid Waste, SW-846, 3rd ed., 1986 and Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989.

2 Comb = Combustion Zone of Underfire Air, OFA = Overfire Air, Sludge Gun = Sludge Atomization Nozzle

Figure 7-13: Bottom Ash Sulfate for Oxygen-Enriched MSW Incineration



7.4 Heat and Material Balance Results (Error Analysis)

A computer program was written to perform heat and material balance calculations for each set of pilot test run data. The program is based on solving a set of atom balances; the solution to the set of equations is an estimate of the composition of the MSW that was burned. Knowing the waste's elemental composition, the higher heating value of the MSW can be estimated, which is further used in the solution of the energy balance. Appendix D-4 contains a sample output of the program and a list of the equations and assumptions.

Table 7-5 is an important summary of the heat and material balance calculations for the successful pilot test runs. The data are presented in two ways. The first column for each test category calculates the heat and material balance closure and MSW composition using all of the measured process data. In the second column for each test category, the flue gas flow and tramp air is adjusted so that the material balance closure is within 1%. Flue gas moisture was also corrected in several Phase II coincineration runs where it was apparent that breakthrough had occurred.[5] The purpose of the second column of data is to provide a better estimate of the MSW composition and higher heating value (HHV) that was actually combusted, and also to assess the error introduced by the manual flue gas Pitot measurement. The heat and material balance calculations for all of the test runs for each of the two cases is presented in Appendices D-5 and D-6.

The results of the heat and material balance calculations for both Phase I and Phase II are encouraging and increase the level of confidence in conclusions drawn from the pilot test data presented in this report. For the uncorrected data, mass balance closure ranged from 3.3 to 12.9% and heat balance closure ranged from -9.1 to 4.5%. Heat leak from the unit was estimated at 150,000 Btu/hr which represents approximately 5% of the total heat input. The calculated heating value of the Phase I MSW ranged from 5400 to 5800 Btu/lb. For Phase II, the calculated heating value of the MSW ranged from 5600 to 7500 Btu/lb. The 7500 Btu/lb heating value is unreasonable and is a result of erroneous flue gas moisture data collected during some of the oxygen-enriched coincineration runs.

For the corrected data, heat balance closure was better, ranging from -4.71 to 3.5% assuming the same heat leak of 150,000 Btu/hr. The corrected MSW HHV for Phase I ranged from 5400 to 5740 Btu/lb and for Phase II ranged from 5440 to 5840 Btu/lb. The corrected data provided more consistent estimates of the MSW composition and heating value.

It is important to note that for all of these calculations, the tramp air flow rate was estimated based on closure of the nitrogen atom balance. The average tramp air for the uncorrected runs is 714 pph, compared to 900 pph for the corrected runs. The tramp air for the corrected data more closely approximates the average measured tramp air flow of 840 pph. Based on this analysis, the average error introduced by the flue gas Pitot measurement was 5.7%.

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[5] Breakthrough occurred when the silica gel absorbent for the flue gas apparatus became saturated with water. By not condensing all moisture contained in the flue gas, the estimates of flue gas moisture were erroneous and low.

Table 7-5
Heat and Material Balance Summary

Phase I		Baseline		O2 Enriched MSW Incineration		O2 Enriched Coincineration	
		Measured	Adjusted	Measured	Adjusted	Measured	Adjusted
MSW	pph	539 - 668	539 - 668	564 - 720	564 - 720	525 - 582	525 - 582
Sludge	pph	0	0	0	0	130 - 170	130 - 170
Oxygen	pph	0	0	50 - 216	50 - 216	100 - 133	100 - 133
dry Sludge/MSW	%					3.8 - 4.5	3.8 - 4.5
MSW Composition, calc'd							
C	%	27.8	28.1	29.2	29.1	29.1	28.8
H	%	3.8	3.8	4.0	3.9	4.0	4.0
O	%	15.4	15.7	14.9	17.3	13.9	14.1
H2O	%	33.9	34.4	31.3	31.4	34.9	35.2
Ash	%	19.1	18.0	20.6	18.3	18.1	17.9
MSW HHV	Btu/Lb	5,390	5,414	5,750	5,517	5,800	5,743
MSW Moisture (1)		22 - 40	22 - 40	22 - 40	22 - 40	31 - 38	31 - 38
Tramp Air	pph	583	869	599	1,071	428	523
Flue Gas (FG) flow	pph	4350	4673	4353	4,891	4288	4395
Adjustment in FG flow	%		7.4		12.4		2.5
Mass Balance Closure	%	6.2	0.3	11.3	0.4	3.3	0.7
Heat Balance Closure (2)	%	1.9	-1.3	-0.1	-2.9	-2.3	-3.1
Number of Runs		4	4	7	7	3	3
Run No.		7A, 8A, 13A, 14A	7A, 8A, 13A, 14A	7B,7C,13B,13C, 14B,14C,9A	7B,7C,13B,13C, 14B,14C,9A	16A, 16B, 17B	16A, 16B, 17B

Table 7-5 (Continued)
Heat and Material Balance Summary

Phase II		Baseline		Coincineration without O2		O2 Enriched Coincineration	
		Measured	Adjusted	Measured	Adjusted	Measured	Adjusted
MSW	pph	575 - 649	575 - 649	552 - 616	552 - 616	583 - 752	583 - 752
Sludge	pph	0	0	235 - 370	235 - 370	235 - 490	235 - 490
Oxygen	pph	0	0	0	0	171 - 328	171 - 328
dry Sludge/MSW	%			5.1 - 11.3	5.1 - 11.3	5.8 - 11.0	5.8 - 11.0
MSW Composition, calc'd							
C	%	28.5	27.7	31.6	30.1	37.3	29.1
H	%	3.8	3.7	4.5	4.3	5.3	4.1
O	%	13.8	13.5	18.9	17.9	18.5	14.2
H2O	%	34.3	36.5	24.1	28.5	13.8	32.9
Ash	%	19.6	18.6	21.0	19.2	25.1	19.7
MSW HHV	Btu/Lb	5,596	5,437	6,147	5,870	7,497	5,842
MSW Moisture (1)		20 - 32	20 - 32	28 - 30	28 - 30	20 - 31	20 - 31
Tramp Air	pph	938	1041	803	965	930	931
Flue Gas (FG) flow	pph	4664	4807	4882	5,100	4743	4944
Adjustment in FG flow	%		3.1		4.5		4.3
Mass Balance Closure	%	4.9	0.1	5.4	0.4	12.9	0.4
Heat Balance Closure (2)	%	0.2	2.4	4.5	3.5	-9.1	-4.7
Number of Runs		4	4	2	2	7	7
Run No.		20,22A,23A,24A	20,22A,23A,24A	22B, 26B	22B, 26B	22C,23B/C 24B/C,25B/C	22C,23B/C 24B/C,25B/C

Notes -

1 Represents the range of of daily trash moisture measurements made during these test days.

2 Assumes a 150,000 Btu/hr heat leak

7.5 Summary of Results

The pilot test to demonstrate "Oxygen-Enriched Coincineration of MSW and Sewage Sludge" can be considered a success. The most significant results are presented below:

1. Sludge and MSW were coincinerated with oxygen-enriched air without affecting carbon burnout in the bottom ash and fly ash. The maximum ratio of dry sludge/MSW processed was 11%. The solids content of the sludge fed to the combustor ranged from 13 to 17%. The oxygen required to maintain baseline operating conditions was 3.5 to 5.5 pounds oxygen per pound of dry sludge.

2. Sludge was successfully coincinerated on a 11.3% dry sludge/MSW basis via the sludge atomization nozzle without oxygen. However, maintaining baseline flue gas excess oxygen without oxygen enrichment resulted in decreased combustion temperatures and increased flue gas flow rate.

3. Enrichment of the combustion grate underfire air to 24% oxygen allowed an increase of the MSW throughput to the unit by approximately 9%. Enrichment of the combustion grate underfire air to 26.9% increased the MSW throughput by approximately 20%.

4. The particle size of sewage sludge introduced into the furnace affected whether or not complete sludge combustion could be achieved. Atomization of the sewage sludge into fine particles reduced its particle size and increased the surface area of the sludge particle to the point where it could be completely combusted.

5. Oxygen enrichment increased the conversion of sulfur contained in the solid wastes to flue gas SO_2.

6. Higher levels of flue gas NO_x measured during straight enrichment and oxygen-enriched coincineration runs was attributed to greater NO_x formation fostered by oxygen enrichment.

7. Changes in flue gas HCl were correlated to the variability in the chlorine content of the solid waste, and not to the addition of sewage sludge.

8. The heavy metal content of the bottom ash and fly ash was, on the average, unaffected by the addition of oxygen and sewage sludge.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Oxygen-enriched coincineration of MSW and sewage sludge has been successfully demonstrated on a pilot scale. After implementation of an innovative sludge atomization nozzle, coincineration of MSW and sewage sludge was achieved without affecting carbon content of the ash, and without significantly affecting important operating conditions such as combustion temperature, flue gas flow rate, and flue gas excess oxygen. The ratio of dry sludge and MSW that was processed ranged from 3.8 to 11%; the maximum ratio was not established. Verifying the predictions of heat and material balance calculations, the optimum oxygen required to maintain baseline operating conditions was estimated at 3.5 to 5.5 pounds oxygen per pound of dry sludge. It was concluded that flue gas emissions such as NO_x and SO_2 may be affected by oxygen enrichment. By optimizing the oxygen/sludge ratio, and the location at which oxygen is introduced into the furnace for coincineration, the effect of this new process technology on flue gas emissions can potentially be minimized. The pilot test demonstrated that the MSW feed rate to the combustor does not need to be reduced to allow for the addition of sewage sludge. Oxygen-enriched MSW incineration tests demonstrated a 20% increase in the MSW combustion rate when the combustion zone underfire air was enriched to 27% oxygen.

Coincineration without oxygen enrichment was also demonstrated up to 11.3% dry sludge/MSW. This level of codisposal exceeds the 2 to 3% demonstrated by conventional coincineration methods. Without oxygen, though, baseline operation cannot be maintained. Combustion temperatures were significantly reduced and the flue gas flow rate increased, as the quantity of sludge to be coincinerated increased.

Oxygen-enriched coincineration of MSW and sewage sludge should be considered a viable sludge disposal technology based upon the results of the pilot demonstration test. The process is recommended for municipalities, especially in the northeast United States, which have been required to develop environmentally safe sludge disposal plans to replace current ocean-dumping and landfilling of their solid wastes. The technology eliminates the need for a municipality to invest in a new sludge disposal facility, and avoids the problem of siting a new facility and the new source of emissions that it would create. The process has shown to be economically attractive to the owner/operator of the W-t-E plants that can be retrofitted into a coincineration facility.

APPENDIX A-1

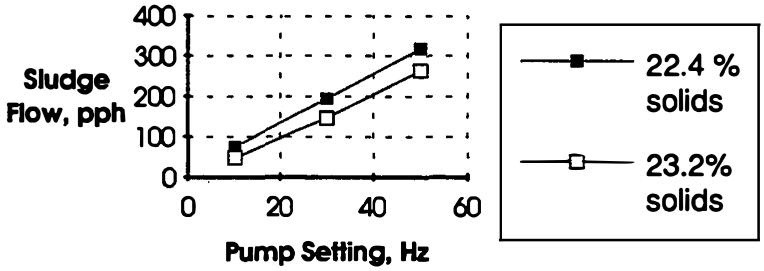
SLUDGE PUMP CALIBRATION DATA - EXTRUSION PLATE FEED SYSTEM

Table A-1.1 Sludge Pump Calibration Data - Phase I

(for Sludge Pump/Sludge Extrusion Plate Feed System)

% Solids Sludge	Pump Setting (Hz)	Time 1 (min:sec)	Time 2 (min:sec)	Weight @ Time 1 (Lbs)	Weight @ Time 2 (Lbs)	Rate (Lbs/hr)	Discharge Pressure (psig)
23.2	10	20:30	30:30	105	113	48	90-100
	30	40:00	44:30	113	124	147	120-140
	50	56:30	64:00	124	157	264	160
22.4	10	17:10	26:00	220	230	75	75
	30	59:50	67:50	194	220	195	100-120
	50	58:30	65:30	157	194	317	170

Figure A-1.1: Sludge Pump Calibration Curve - Phase I



APPENDIX A-2

SLUDGE PUMP CALIBRATION DATA - ATOMIZATION NOZZLE FEED SYSTEM

Table A-2.1 Sludge Pump Calibration Data - Phase I *

(for Sludge Pump/Sludge Atomization Nozzle Feed System)

% Solids Sludge	Pump Setting (Hz)	Elapsed Time (min:sec)	Final Weight (Lbs)	Initial Weight (Lbs)	Rate (Lbs/hr)	Discharge Pressure (psig)
14.5	10	20	197	168	87	25
	20	12	125	91	170	32
	30	10	168	125	258	35
	40	8	243.5	197	349	38

* Calibration performed with no atomizing air.

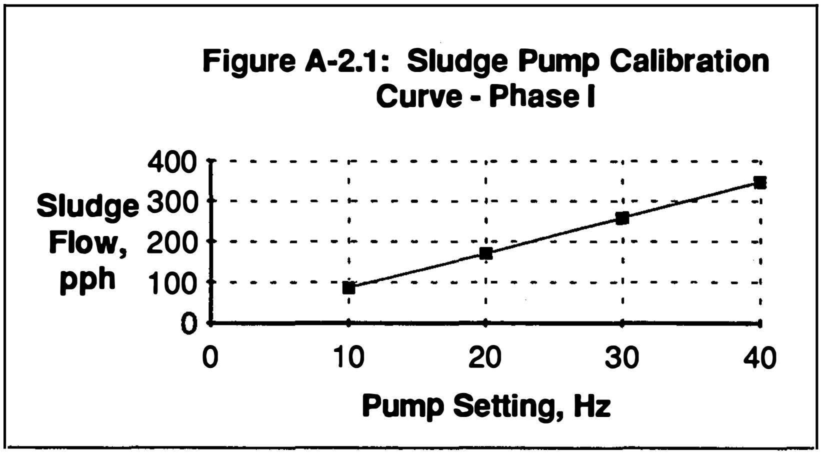
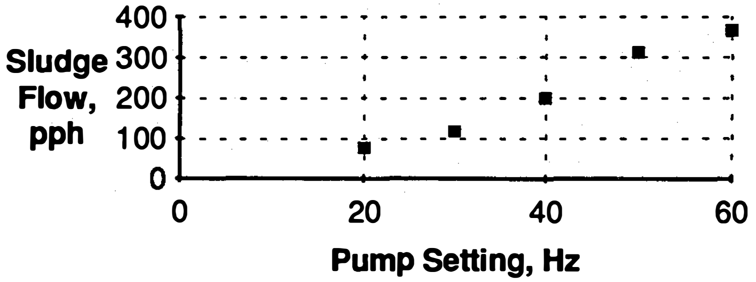


Table A-2.2 Sludge Pump Calibration Data - Phase II

(for Sludge Pump/Sludge Atomization Nozzle Feed System)

% Solids Sludge	Pump Setting (Hz)	Elapsed Time (min:sec)	Final Weight (Lbs)	Initial Weight (Lbs)	Rate (Lbs/hr)	Discharge Pressure (psig)
16.5	20	10	294	268	78	44
	30	6	133.5	110	118	48
	40	6	219	185.5	201	48
	50	6	185.5	144	311	50
	60	6	268	219	368	68

Figure A-2.2: Sludge Pump Calibration Curve - Phase II



APPENDIX A-3

OXYGEN FLOW SKID CALIBRATION DATA

Table A-3.1: Calibration Data for Flow Skid A - Phase I (Combustion Zone Underfire Air)

Regulator Pressure (psig)	Rotameter	Flow Rate (scfh)	Flow Rate (pph)
25	0	0	0
25	10	200	16.6
25	20	400	33.1
25	30	600	49.7
25	40	800	66.3
25	50	1000	82.8
25	60	1200	99.3
25	70	1400	115.9
25	80	1600	132.5
25	90	1800	149
25	100	2000	165.6

Table A-3.2: Calibration Data for Flow Skid B - Phase I (Burnout Zone/Overfire Air)

Regulator Pressure (psig)	Rotameter	Flow Rate (scfh)	Flow Rate (pph)
15	0	0	0
15	10	85	7
15	20	170	14.1
15	30	255	21.1
15	40	340	28.1
15	50	425	35.2
15	60	510	42.2
15	70	595	49.3
15	80	680	56.3
15	90	765	63.3
15	100	850	70.4

Table A-3.3: Calibration Data for Flow Skid B - Phase I
(Burnout Zone/Overfire Air)

Regulator Pressure (psig)	Rotameter	Flow Rate (scfh)	Flow Rate (pph)
45	0	0	0
45	10	120	9.9
45	20	240	19.9
45	30	360	29.8
45	40	480	39.7
45	50	600	49.7
45	60	720	59.6
45	70	840	69.5
45	80	960	79.5
45	90	1080	89.4
45	100	1200	99.3

Table A-3.4: Calibration Data for Flow Skid B - Phase II
(Overfire Air)

Regulator Pressure (psig)	Rotameter	Flow Rate (scfh)	Flow Rate (pph)
40	100	2500	207
60	100	2950	244
80	100	3300	273
100	100	3650	302
125	100	4000	331

Table A-4.5: Calibration Data for Flow Skid B - Phase II
(Sludge Atomization Nozzle)

Regulator Pressure (psig)	Rotameter	Flow Rate (scfh)	Flow Rate (pph)
40	100	3485	288
60	100	4750	393
80	100	6010	498
100	100	7275	602

APPENDIX B-1

UNDERFIRE AND OVERFIRE AIR ORIFICE PLATE CALIBRATION CURVES

Figure B-1.1: Calibration Curve for Secondary Air

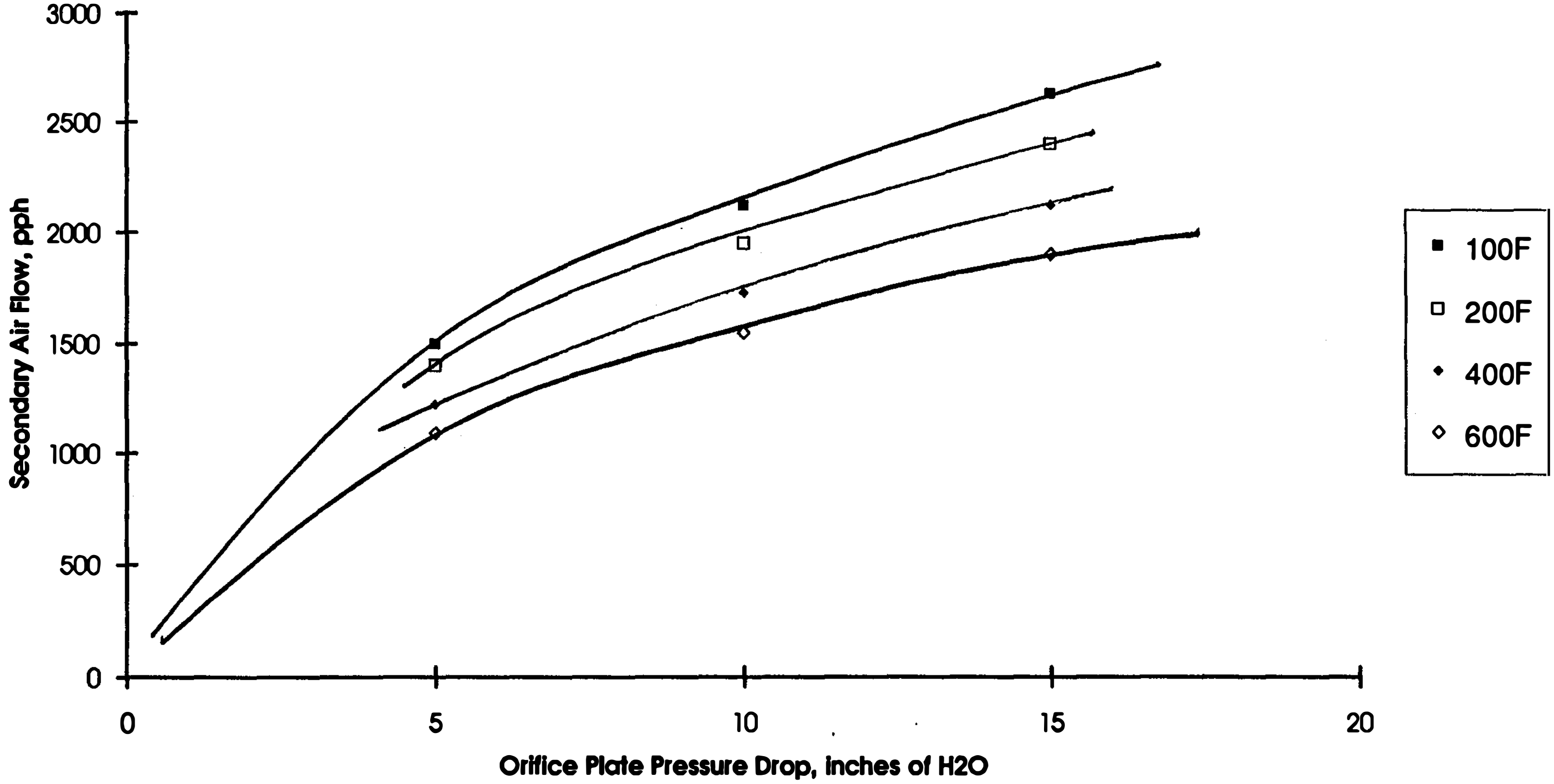


Figure B-1.2: Overfire Air Calibration Curve

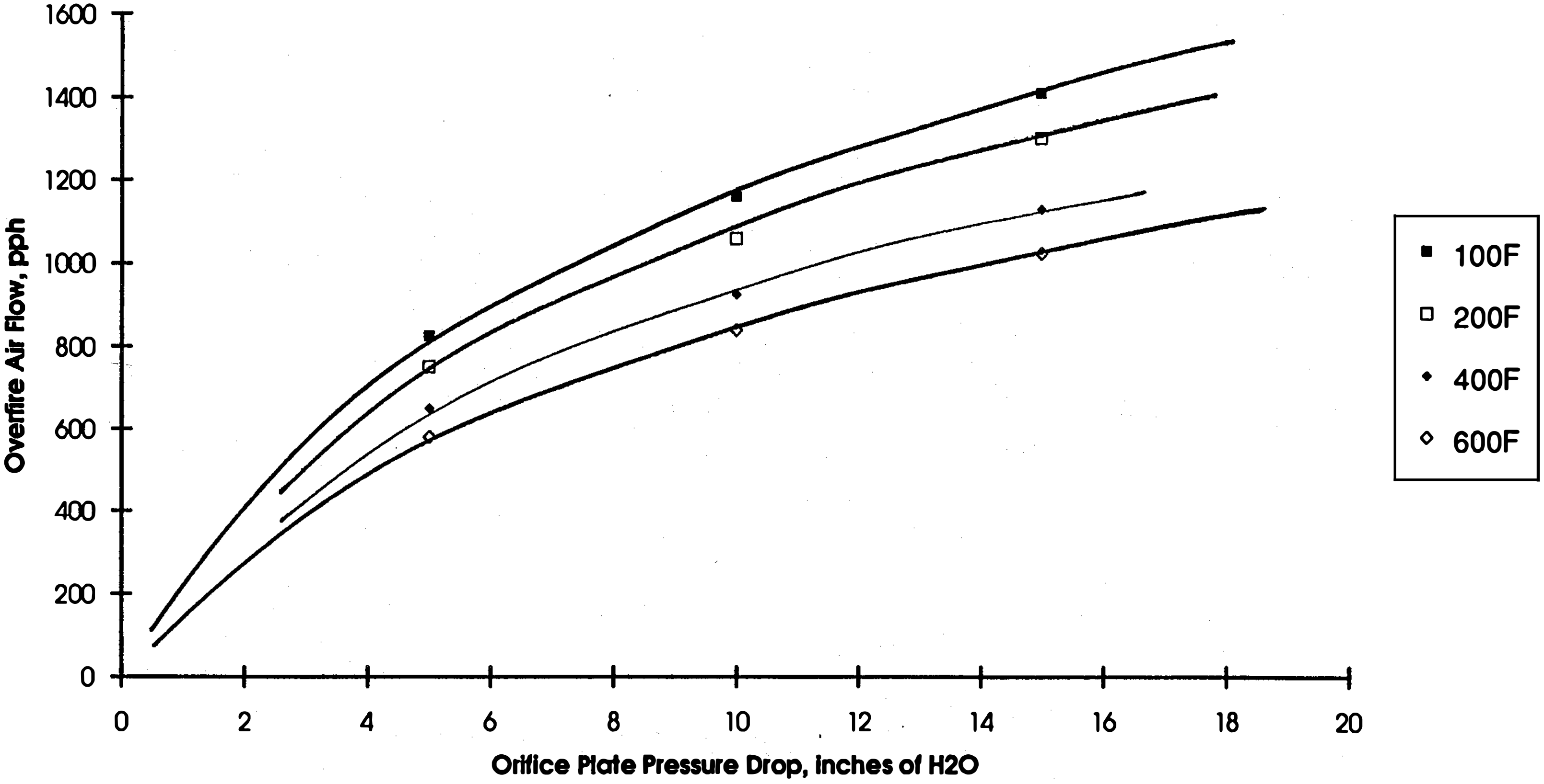
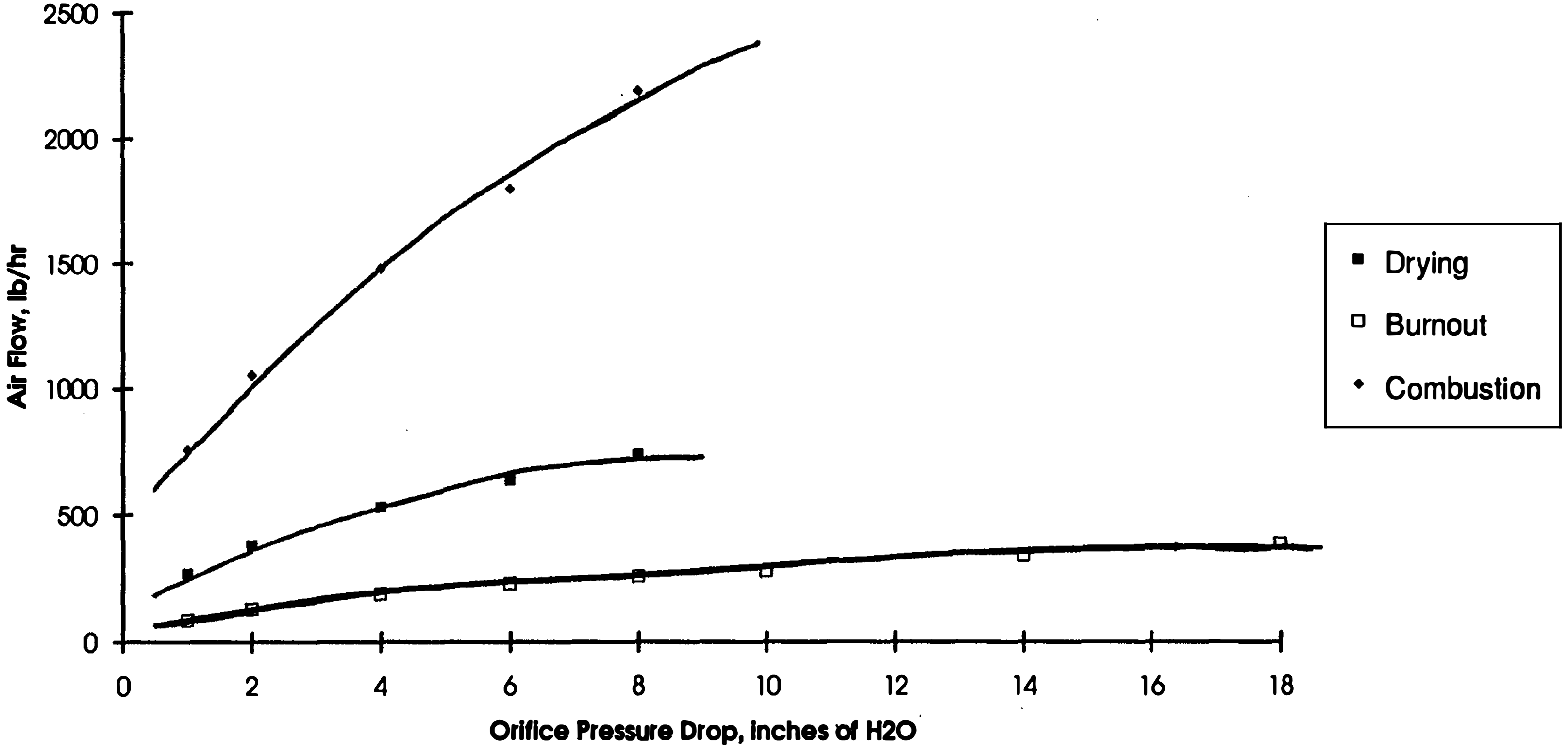


Figure B-1.3: Grate Air Calibration Curves



APPENDIX B-2

FLUE GAS FLOW PITOT TRAVERSE - EQUATIONS AND SAMPLE CALCULATION

APPENDIX B-2: FLUE GAS FLOW PITOT TRAVERSE EQUATIONS

Given: Flue Gas Duct 10" Schedule 80
diameter = 9.75" I.D.
area (x-section) = 0.5185 ft2

Measured: Traverse Pitot $P_{(1-14)}$ (in W.C.)
Flue Gas Duct Pressure (in W.C.)
Furnace Temperature (°F)

Equations:

h_v = $(P_n^{0.5}/14)2$ for n=1,14 in W.C.

V_{FG} = $1096.7\ ((h_v/pFG)$ ft/min

FG Flow = (VFG)(0.5185 ft2) acfm

= FG flow(acfm)(pFG)(60min/hr) pph

RILEY STOKER CORPORATION, WORCESTER, MASS.

COMPUTED BY.................. DATE.................. CONTRACT NO.................. PAGE NO..................
CHECKED BY.................. DATE.................. SUBJECT ....
REVIEWED BY .... DATE.................. SAMPLE DATA SHEET
APPROVED BY.................. DATE..................

PITOT TRAVERSE RECORD

FLUE GAS DUCT 10" SCH 80
DIAMETER 9 3/4" I.D.
DUCT A_c - 0.5185 FT^2

DATE - 2/26/92
TIME - 18:25
TEST DESCRIPTION - SLUDGE / MSW w/o O_2

POINT	PORT 1	PORT 2
1	.26	.28
2	.34	.39
3	.42	.42
℄	.42	.43
4	.43	.41
5	.38	.37
6	.33	.30

FLUE GAS TEMP. -

FLUE GAS DUCT PRESS. - -1.6 "H_2

$R_T MSQ\ V_{P\,AVG}$ -

FLUE GAS VELOCITY - Ft/

FLUE GAS FLOW RATE - 1677 ACF

CORRECTED FLUE GAS FLOW RATE

4253 pph - 945 SCF

FLUE GAS DENSITY -

MEASURED MOISTURE CONTENT -

CALCULATED MOISTURE CONTENT -

$$V_{FG} = 1096.7 \sqrt{\frac{h_v}{\rho_{FG}}}$$

$$\rho_{FGA} = \frac{(\rho_{FG})(530)}{(460+T)} \times \frac{(P_B - P)}{P_B} \ \frac{lb}{Ft^3}$$

$$P = P_{FG} / 13.6$$

TOTAL AIR FLOW RATE -

MSW FEED RATE -

FLUE GAS COMPOSITION (DR

CO_2	CO
O_2	SO_2
N_2	NO_x
	HCl

FORM STOCK

APPENDIX B-3

FLUE GAS MOISTURE - EQUATIONS AND SAMPLE CALCULATION

APPENDIX B-3: FLUE GAS MOISTURE EQUATIONS

Measured Variables:

Time (Start, End)	(hr:min)
Flue Gas Meter (FG) (initial, final)	(ft^3)
Condensing Coil Weight (CC) (initial, final)	(grams)
Silica Gel Bed Weight (SB) (initial, final)	(grams)
Sample Pressure	(in. W.C.)
Sample Temperature	(° F)

List of Equations:

1. Total Water Accumulated (scf)

$$\text{H2O (scf)} = \text{CC}_{(\text{final-initial})} + \text{SB}_{(\text{final-initial})}(\text{lb}/454\text{g})(\text{lbmol}/18\text{lb})(387\text{scf}/\text{lbmol})$$

2. Flue Gas Flow (scf,dry)

$$\text{FG (scf,dry)} = \frac{\text{FG}_{(\text{final-initial})}(\text{Sample P}/13.6\text{in W.C.}/\text{inHg} + \text{Pbarm})(387\text{scf}/\text{lbmol})}{(29.92\ \text{inHg}/\text{atm})(460\ \text{R} + \text{Sample T})(0.7302\ \text{ft}^3\ \text{atm}/\text{lbmol R})}$$

3. Flue Gas Moisture (%)

$$\text{FG H2O (wt\%)} = \text{H2O (scf)} / ((\ \text{FG (scf,dry)} + \text{H2O (scf)})$$

RILEY STOKER CORPORATION, WORCESTER

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REVIEWED BY .... DATE .... SAMPLE DATA SHEET
APPROVED BY .... DATE ....

FLUE GAS MOISTURE ANALYSIS DATA SHEET.

DATE: 2/26/92
TIME: 5:30 PM
TEST DESCRIPTION: SLUDGE NO
3RD RUN
SAMPLE TEMP: 81°F 98°F
SAMPLE PRESS: 7.1"W.C. 7.2

METER IS DRY GAS METER

START TIME	END TIME	ELAPSED TIME
5:36 PM	6:31	55 MINS
INITIAL MTR	FINAL MTR	TEST FLOW
143 3	280.6	137.3 (DRY)
INITIAL COND WEIGHT	FINAL COND WEIGHT	COND. WATER
2661	3125	464
INITIAL Si WEIGHT	FINAL Si WEIGHT	ABSORBED WATER
2630	2660	30

AVG FG MOL WT
27.74#/MOL

TOTAL WATER RECOVERED - 494 gms

FLUE GAS MOISTURE CONTENT 15.20 %

FLUE GAS ANALYSIS (DRY)

START OF TEST		END OF TEST	
CO_2	8.9	CO_2	10.1
O_2	10.5	O_2	9.2
N_2	80.6	N_2	80.7

N_2 BY DIFFERENCE

APPENDIX C-1

CEMS INSTRUMENTATION

Teledyne M/N 326RB
O2 ANALYSER

1. INTRODUCTION

1.1 Purpose. The Teledyne Analytical Instruments (TAI) Series 326B Oxygen Analyzer was specifically designed to perform the analytical role in TAI's Model 9500 Flue Gas System. The analyzer may also be used as a separate entity to perform oxygen measurements ranging from one (1) to one hundred (100) percent oxygen in virtually any parent gas.

1.2 Method of Analysis. The analyzer employs TAI's patented Micro-fuel Cell (U.S. Pat #3,429,796) to provide an electrical signal that is directly proportional (and specific) to the oxygen concentration in the gas phase immediately adjacent to its sensing surface.

The Micro-fuel Cell is incapable of producing a significant electrical signal in the absence of oxygen. This unique feature obviates the necessity of having to employ an expensive, cumbersome, questionable gas to "zero" standardize the instrument.

As a further convenience, one of the three (3) available ranges of analysis is always 0-25% so that air (20.9% oxygen) may be used to calibrate the sensitivity of the analyzer. Again, this obviates the expense and doubt accompanying the use of so-called "certified" gas mixtures for calibration purposes.

The Micro-fuel Cell is a completely enclosed, maintenance-free device with a predictable life span that is covered by warranty. When the cell is expended, it is thrown away as one would discard a worn-out flashlight battery. TAI's extensive line of Micro-fuel Cell equipped oxygen measuring instruments are all designed so that the cell may be replaced in a matter of moments by non-technical personnel without the use of tools.

1.3 Configuration. The instrument is housed in a fiberglass equipment case that will resist the invasion of moisture and dust. When fulfilling its primary function in the Model 9500 Flue Gas System, the analyzer is an integral part of a back plate assembly which is housed in a large equipment enclosure and as such, has been designed to project from, rather than be flush with, its mounting surface.

Models supplied independent from the Model 9500 Flue Gas System may be equipped with an optional integral sample control panel that features a toggle valve controlled input manifold for the selectionof span (air) and sample gas as well as a throttle valve and flowmeter for sample path flow control.

TELEDYNE M/N 326RB
O2 ANALYSER

1.4 Standard Features. The following features are standard in the Series 326B line of analyzers. Instruments equipped with only these features are identifiable by the basic number of the series, i.e., Model 326B.

1.4.1 Three Ranges of Analysis. The standard ranges of analysis are 0-5, 0-10, and 0-25% oxygen. Range control is achieved through the positioning of a control panel mounted selector switch. The standard ranges have been selected to best cover the oxygen content of flue gas. Upon request, any three ranges of analysis from 0-1 to 0-100% can be provided.

1.4.2 Integral Meter Readout. All models of the Series 326B are equipped with an exceptionally accurate 5 inch panel meter for direct readout of the analysis. A linear scale (mirror equipped to eliminate parallex) promotes reliable, accurate readout of the analysis at any point on the scale. The resolution and accuracy of the instrument's meter obviates the necessity of an accessory readout device--unless permanent recording or remote indication is required.

1.4.3 Output Signal. For those applications requiring a remote indication and/or recording of the sample oxygen, a linear output signal of from 0-1 millivolt to 0-1 volt D.C. is available at no extra charge. The desired magnitude of signal should be specified at the time of purchase. Unless otherwise specified, the output signal will be 0-1 volt D.C.

The output signal is not suitable for driving low impedance devices. Accessory equipment must have an input impedance of 10,000 ohms or more.

1.4.4 Temperature Control and Compensation. To eliminate the inaccuracies caused by varying temperature conditions that are inherent in most methods of analysis employing transducers, a system composed of a combination of tempertaure compensation and control is used in the Series 326B.

Teledyne M/N 326RB
O_2 ANALYSER

7. APPLICATION DATA

7.1 TAI SALES ORDER NUMBER:

7.2 INSTRUMENT MODEL NUMBER:

7.3 INSTRUMENT SERIAL NUMBER:

7.4 MICRO-FUEL CELL CLASS:

7.5 ACCURACY: ± 1% of scale at constant temperature; ± 1% of scale or ± 5% of reading, whichever is greater, over the operating temperature range.

7.6 RESPONSE AND RECOVERY: At the specified flowrate 2 scfh), 90% in seconds.

7.7 OPERATING TEMPERATURE RANGE: 0-125°F.

7.8 RANGES OF ANALYSIS:

7.9 OUTPUT SIGNAL VOLTAGE:

7.10 OUTPUT SIGNAL CURRENT:

7.11 ALARM SET POINT #1:

7.12 ALARM SET POINT #2:

8. SPECIAL FEATURES:

906528

GENERAL DESCRIPTION

HORIBA CO & CO_2

The Horiba Model PIR-2000 General Purpose Infrared Gas Analyzer is a precision gas analyzer based on nondispersive infrared ray absorption for continuously determining the concentration of a given component in a gaseous stream.

It is designed to effectively perform continuous monitoring and component analysis in the process control industry and in various other fields such as ambient air, stationary source and vehicle exhaust emissions monitoring. It is also utilized for monitoring the simulated environment used in agricultural studies for plant growth control.

Before operating this instrument, it is recommended that the user read through this instruction manual to insure efficient operation and accurate results.

Repeatability.	±0.5% Full Scale
Span Drift	±1%/24 hour Full Scale, ±5°C
Zero Drift	±1%/24 hour Full Scale, ±5°C
Response Speed (Electrical). .	0.5, 1.2, 3.0 and 5.0 seconds selectable. 0.5 seconds is standard
Ambient Temperature.	0-40°C (Operating temp.) -5°C to 50°C (the drift may increase threefold between -5°C to 0°C and 40°C to 50°C. An extended operation at temp. over 40°C may shorten the service life of electrical components).
Power Requirement.	Any one of the following: 100, 115, 220, or 240 VAC, ±10%, 50/60 Hz (to be specified)
Output (Nonisolated)	0-10mV, 0-100mV, 0-1V, 0-5V
Output (Isolated) Optional . .	4-20mA, 500 ohms maximum load
Sample Gas Flow Rate	1 to 3 SCFH
Flowing Reference Cell (Optional)	
Reference Gas Flow Rate. . . .	1 SCFH (Approximately)
Indicator.	Scale Length: 120mm, equally divided into 100 divisions
Panel Cutout Size.	9-9/16" (243mm) x 7-1/32" (179mm)
Range I.D. Signal.	Dry contact closure. Contact rating: 100mA, DC 24V or 100mA, AC 115V
Range Ratio.	1:10 Amp Voltage
Ranges	Three ranges, as specified from the following table:

GAS		MEASURING RANGE (Full Scale Concentration)		
		Minimum * Possible	Minimum ** Recommended	Maximum
CO	Carbon Monoxide	150 ppm	500 ppm	100%
CO_2	Carbon Dioxide	20 ppm	200 ppm	100%
NO	Nitric Oxide	250 ppm	1000 ppm	100%
SO_2	Sulphur Dioxide	100 ppm	400 ppm	100%
CH_4	Methane	100 ppm	400 ppm	100%
C_3H_8	Propane	100 ppm	400 ppm	100%
C_6H_{14}	n-hexane	100 ppm	400 ppm	5%
NH_3	Ammonia	300 ppm	1000 ppm	100%

CATALOG NUMBER 194104 MODEL 400A HYDROCARBON ANALYZER

SPECIFICATIONS STANDARD ANALYZER

Fullscale Sensitivity	Adjustable from 4 p/10^6 CH_4 to 10% CH_4
Fuel Gas Requirements	75 to 80 cc/min premixed fuel consisting of 40% hydrogen and 60% nitrogen or helium (THC <0.5 p/10^6 supplied at 25 to 50 psig (172-344 kPa)
Sample Gas Requirements	0.35 to 3.0 liters/minute at 15 to 25 psig (103 to 172 kPa)
Burner Air Requirements	350 to 400 cc/min of zero grade (THC <1 p/10^6) air. supplied at 25 to 50 psig (172-344 kPa)
Sample Bypass Flow	0.3 to 3.0 liters/minute
Stability	Electronic stability at maximum sensitivity is ±1% of F.S. throughout ambient temperature range of 32 °F to 110 °F (0 °C to 61 °C). Built-in temperature controller minimizes effect of ambient temperature variations on internal flow and electronic systems.
Reproducibility	1% of fullscale for successive identical samples
Range	RANGE Switch has 8 positions: 1. 2.5. 10. 25. 100. 250. 1000 and REMOTE. In addition. SPAN Control provides continuously variable adjustment within a dynamic range of 4:1.
Response Speed	90% of fullscale within 0.6 seconds with sample bypass flow at 3 liters/minute
Ambient Temperature	32 °F to 110 °F (0 °C to 43 °C)
Ambient Humidity	95% relative humidity. but not in excess of 34 °C wet bulb temperature
Line Voltage	117 VAC ± 10%. 50/60 Hz (220 VAC ± 10% 50/60 Hz Option)
Power Consumption	200 watts max
Output	1) 0 to 5 VDC. 0 to 1 VDC. 0 to 0.1 VDC fully buffered - standard [for 0 to 100.0%] 2) 4 to 20 maDC isolated voltage to current - optional (max load resistance 700 ohms) [for 0 to 100.0%] 3) 0 to 5 VDC accessory output unbuffered - standard [for 0 to 100.0%] available when current option is not used

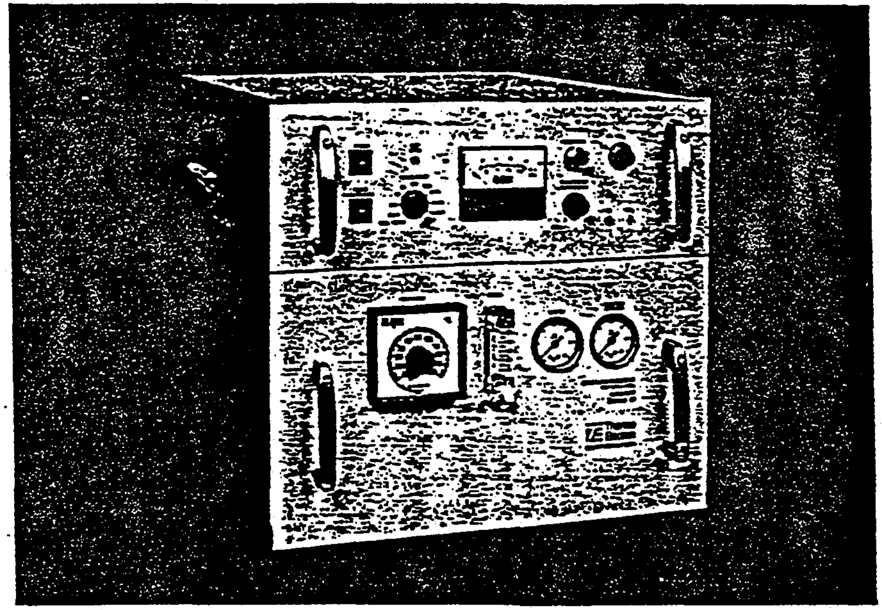
SPECIFICATIONS STANDARD ANALYZER

Safety Features	Flame-on indication and automatic flame-out fuel shutoff is standard.
Contacts	Form A contact operates in parallel with flame-out fuel shut-off solenoid contact rating (24 VDC @ 1 amp) for sample shut-off by customer.
Temperature Control	Set point maintained at 118 °F (48 °C)
Data Display	3 1/2 digit LED characters 0.52 in. high - range 0000-1999
Range Display	1 digit LED 0.52 in. high (1-7 normal ranges. 0-remote control)
Remote Range Control	Standard. fully isolated range control and range ID is optional
Size	18-3/4 in. wide x 8-3/4 in. high x 15-5/8 in. deep (47.6 cm wide x 22.2 cm high x 39.7 cm deep). Recommended panel cutout is 17-3/4 in. wide x 8-1/4 in. high (45.1 cm wide x 21.0 cm high). May be mounted in 19 in. standard rack mounting panel.
Approximate Weight	Net: 22 pounds (10 kg); Shipping: 35 pounds (16 kg)

Thermo Electron
CORPORATION
Environmental Instruments Division

Chemiluminescent NO/NO_x Analyzer

THE WILBUR COMPANY
2 PULPIT RUN
MHERST, NEW HAMPSHIRE 03031
(603) 672-0522



Model 10

For Continuous Source Gas Monitoring

Thermo Electron's Model 10 NO/NO_x Analyzer is based on the chemiluminescent reaction between nitric oxide (NO) and ozone (O_3) according to the reaction:

$$NO + O_3 - NO_2 + O_2 + h\nu$$

Light emission results when the electronically excited NO_2 molecules revert to their ground state.

A front panel mode switch provides for either a direct readout of the NO concentration in the sample being analyzed ("NO" mode) or the total NO_x concentration ("NO_x" mode). When the Model 10 is placed in the "NO_x" mode, the sample stream passes through a NO_x-to-NO converter prior to entering the reaction chamber for subsequent analysis.

Key Features

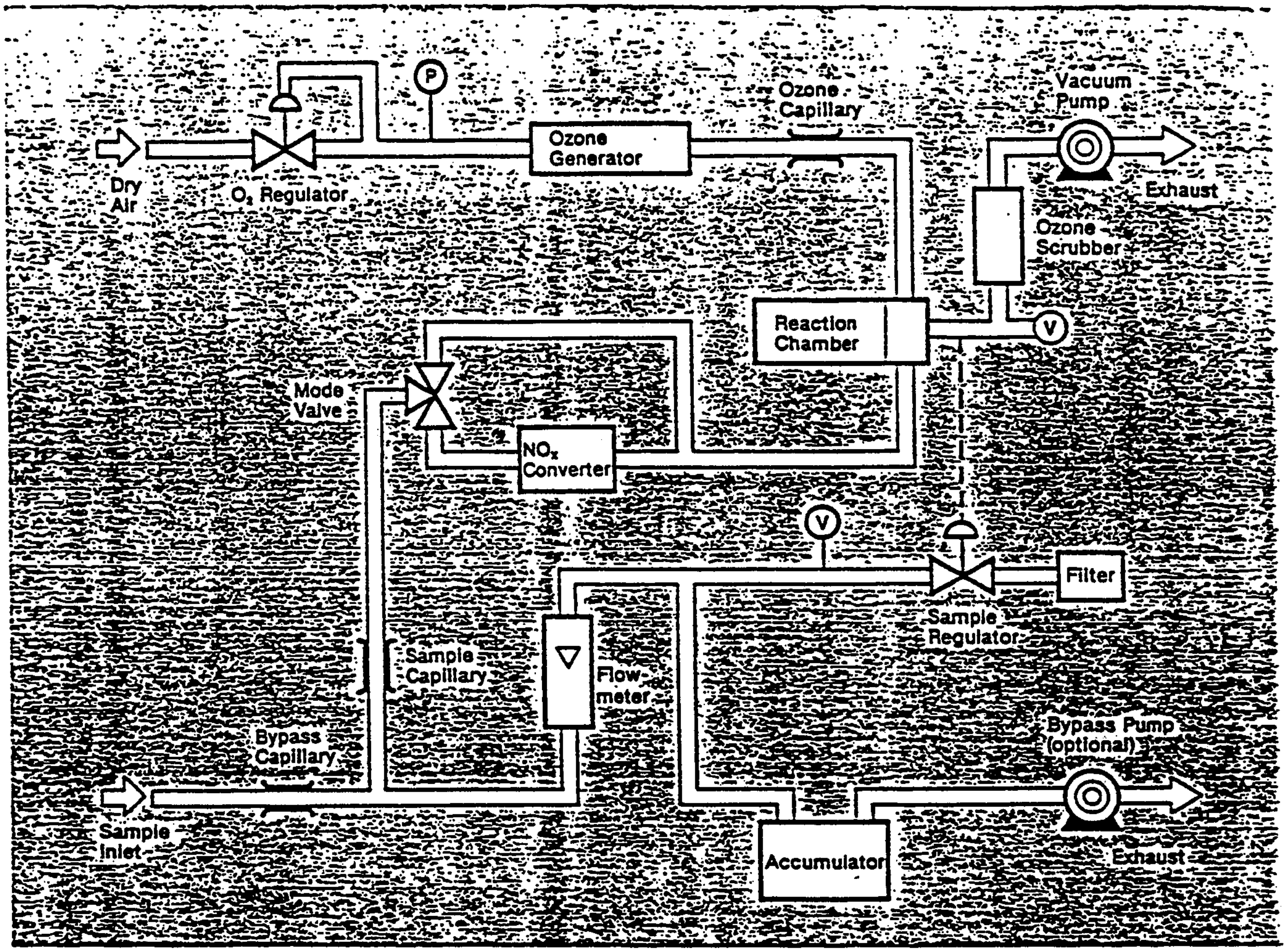
- Selective detection of NO or NO_x
- Eight ranges, from 2.5 to 10,000 ppm FS
- Continuous monitoring with rapid response
- Linear on all ranges
- Field proven reliability
- Insensitive to changes in sample flow

Model 10 Specifications*

Ranges	0–2.5 ppm 0–250 ppm 0–10 ppm 0–1000 ppm 0–25 ppm 0–2500 ppm 0–100 ppm 0–10,000 ppm
Minimum Detectable Concentration	.05 ppm
Noise	Less than 1% of FS
Reproducibility	1% of FS
Operating Temperature Extremes	0–40°C
Response Time (0–90%)	–1.5 second NO mode –1.7 second NO_x mode
Zero Stability	± 1 ppm in 24 hours
Span Stability	± 1% in 24 hours
Linearity	± 1% from 0.05 to 10,000 ppm**
Power Requirements	1000 watts, 115 ± 10 volts, 60 Hz standard. Also available in 115V 50 Hz, and 210 ± 15 volts, 50 Hz versions
Physical Dimensions	19" wide × 17" high × 20" deep
Instrument Weight	75 lbs. (including pump)
Outputs	Two standard outputs supplied: 1) 0–10V; 2) Field selectable from 0–10V, 5V, 1V, 100mV or 10mV. (ma options available.)

*Specifications are typical and subject to change without notice.
**With O_2 Feed: With dry air, linearity to 2000 ppm.

Model 10 Flow Scheme



As illustrated in the above diagram, sample gas enters the Model 10, flows through the bypass capillary, and divides. Most of the sample flows through the flowmeter, accumulator, bypass pump, and exhausts. Only a small amount of sample flows through the sample capillary for analysis. The bypass pump in conjunction with the sample regulator maintain a constant pressure differential across the sample capillary, thus maintaining constant sample flow for analysis. This plumbing network makes the analyzer insensitive to pressure fluctuation in the sample inlet.

From the sample capillary, the sample to be analyzed is either directed through the NO_x to NO converter or around it, depending on the choice of the operator. In the reaction chamber the sample reacts with ozone to produce the light emission and is exhausted. The ozone is produced internally from dry air entering through the oxygen regulator and ozonator. The light emission is sensed by the photomultiplier tube and amplified.

Options

10-001 Bypass pump assembly includes pump, shock tray, accumulator, tubing, and fittings.

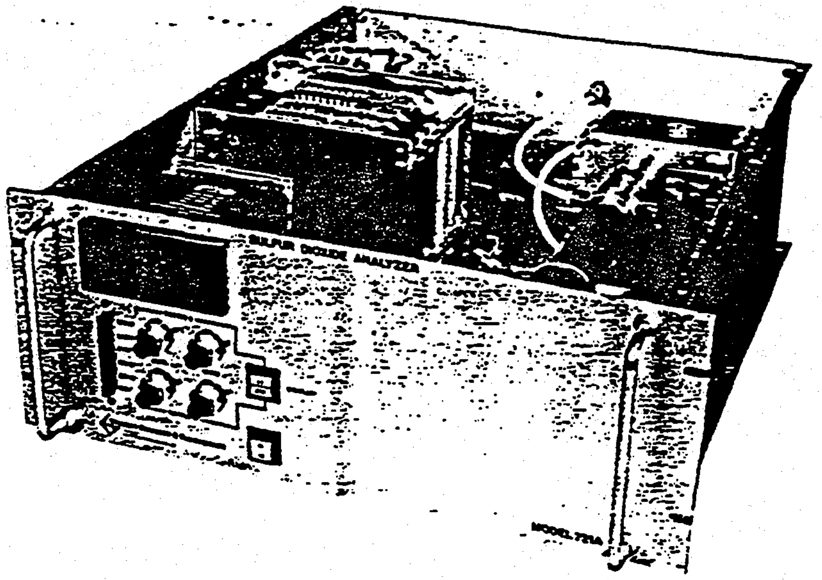
Accessory Instruments

Model 700 Heated Capillary Module
Model 606H Heated Particulate Filter
Model 800 Sample Gas Conditioner
Model 900 Sample Gas Conditioner

Thermo Electron
CORPORATION
Environmental Instruments Division
108 South Street
Hopkinton, MA 01748
Telephone (617) 435-5321
Telex 948325

Printed in U.S.A. - 11 '85 5M

Dual Range SO_2 Analyzer



MODEL 721

Features:

- Chopped optical beam minimizes common mode noise.
- Two continuous measuring channels from a single source, sample cell and detector provide true simultaneous dual range SO_2 concentration measurement.
- Non-interacting zero/span for each measuring channel.
- Common reference channel.
- Outputs linear with concentration.
- Single and Dual range models available with or without front panel accessible adjustments and digital concentration display.
- Convenient 19" CEMA/NEMA 1 enclosure.
- Response - less than 5 seconds to 95% of full scale.
- Built-in test points.
- Modular plug-in design.
- Models without front panel display and adjustments are designed for multi-component computer controlled monitoring systems.

Applications:

- FGD inlet/outlet streams.
- CEM systems.
- Mobile compliance monitoring systems.
- Accurate analysis of widely varying concentrations.
- Laboratory standard.
- Bench scale, pilot plant studies.

Western Research

Description:

The Western Research Model 721 SO_2 analyzer is the only ultra violet photometric analyzer on the market today that provides true, simultaneous, dual range analysis on a continuous basis. This unique analyzer, designed to meet the stringent source monitoring requirements of the California Air Resources Board, is ideal for both dedicated single source applications and multi-source time-shared applications or for use in mobile monitoring units. Now for the first time it is possible to measure normal operating concentration levels and upset condition levels with no interruption, adjustment or loss of accuracy. Both measurement channel output signals are continuously available.

Specifications:

- Accuracy: ±2.0% of full scale worst case - typically better than ±1.0% of full scale.
- Sensitivity - better than 0.5% of full scale.
- Response: Less than 5 seconds to 95% of full scale.
- Linearity: ±1.5% of full scale.
- Minimum full scale concentration.
  - low range 0-250 ppm.
- Range Ratio: 1:1 up to 1:20 available.
- Output signals: Field selectable potentiometric outputs of 0-100 Millivolt. and 0-1 volt provided at rear mounted screw-type terminal strip.
- Power Requirements - 115v/1ϕ/60 Hz - less than 50 watts.
- Weight - 27 lbs.
- Operating Temperature - +5°C to +40°C.
  (41°F to 104°F).
- Calibration: electronic or reference gas.
- Operating Pressure: Well regulated sample required - any pressure up to 1000 psig.

Options:

- Model 721 - Dual range, no front panel mounted display or adjustments.
- Model 721A - Dual range c/w front panel mounted display and adjustments.
- Model 722 - Single range, no front panel mounted display or adjustments.
- Model 722A - Single range c/w front panel mounted display and adjustments.
- Ambient temperature compensated outputs.
- Isolated, self-powered, 4-20 ma outputs (maximum 1000 ohm load).
- Chassis slides.
- 0-100 mV and 0-10 volt instead of 0-100 mV and 0-1 volt.

Western Research
Division of
Bow Valley Resource Services Ltd.

1313 - 44th Avenue N.E.
Calgary, Alberta, Canada
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Telex: 03-827569

Printed in Canada 07/85

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APPENDIX C-2

FLUE GAS HCl ANALYZER

Thermo Environmental Instruments Inc.

Gas Filter Correlation HCℓ Analyzer

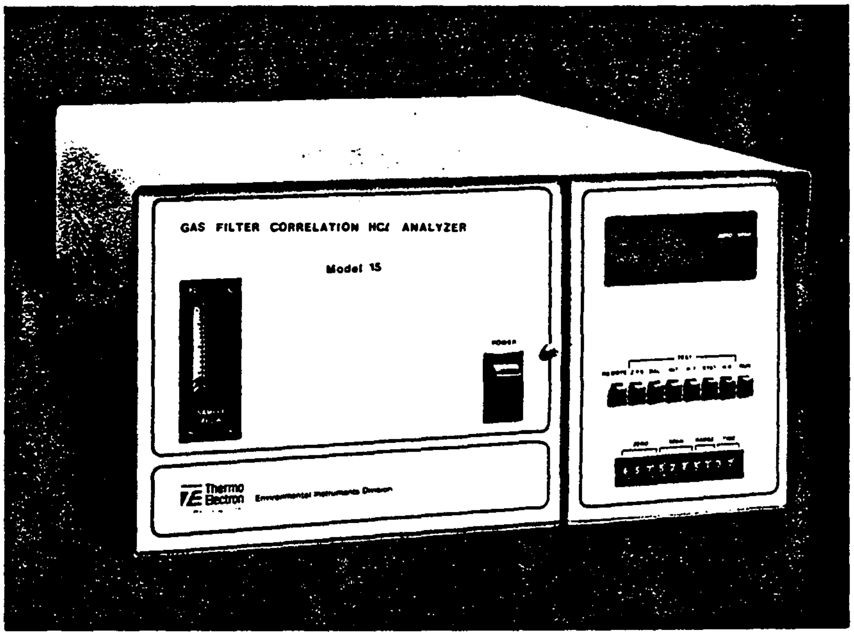
Model 15

For Continuous Monitoring

Thermo Environmental's Microprocessor Based Model 15 HC ℓ Analyzer provides unequaled ease of operation, reliability, precision and specificity. The unique Gas Filter Correlation principle of operation offers the significant advantages of unequaled specificity and sensitivity and increased resistance to shock and vibration.

Key Features

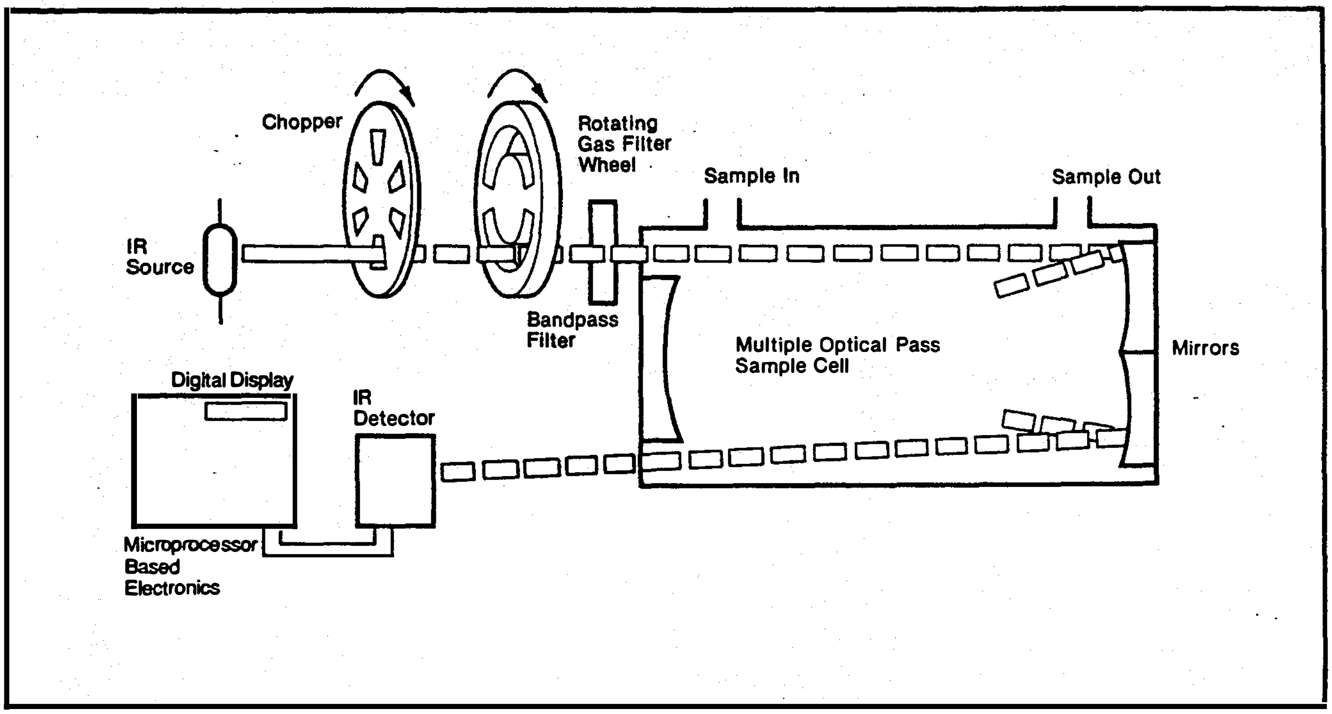
- Microprocessor Based
- Automatic pressure and temperature correction
- Dual fully independent outputs standard
- Hourly average output standard
- Wide dynamic range
- Long term zero and span stability
- Vibration and shock resistant
- Powerful diagnostics made possible by microprocessor
- Linear through all ranges
- Unaffected by changes in flow
- Self-aligning optics



Model 15 Specifications

Ranges	0–5, 0–10, 0–20, 0–50, 0–100, 0–200, 0–500, 0–1000, 0–2000, 0–5000 PPM
Zero Noise	0.1 ppm RMS (5 min. integration time)
Minimum Detectable Limit	0.2 ppm (5 min. integration time)
Zero Drift, 24 Hours	± 0.2 ppm
Span Drift, 24 Hours	± 2% Full scale
Rise/Fall Times (0–90%) (at 1 LPM flow, 30 second integration time)	2 minutes
Precision	± 0.2 ppm
Linearity	± 2% Full scale
Flowrate	1 LPM standard
Operating Temperature	Performance specifications maintained over the range 10–40°C
Power Requirements	100 Watts 105–125 Vac, 60Hz, 220–240 Vac, 50Hz
Physical Dimensions	17″ wide x 6¾″ high x 23″ deep
Weight	45 lbs
Dual Outputs (standard) (Independent Range and Integration Time)	Available 0–100MV 0–1V, 0–5V, 0–10V; digital display, 1 hour integrated value. Other outputs available upon request (4–20MA, IEEE 488)

Specifications subject to change without notice



Principle of Operation

The basic components of a Gas Correlation System are illustrated in the above diagram. Radiation from an infrared source is chopped and then passed through a gas filter which alternates between HCℓ and N_2 due to Rotation of the filter wheel. The radiation then passes through a narrow bandpass filter and a multiple optical pass sample cell where absorption by the sample gas occurs. The IR radiation exits the sample cell and falls on a solid state IR detector.

The HCℓ gas filter acts to produce a reference beam which cannot be further affected by HCℓ in the sample chamber. The N_2 side of the filter wheel is transparent to IR radiation and therefore produces a measure beam which can be absorbed by HCℓ. The chopped detector signal is modulated by the alternation between the two gas filters with an amplitude dependent on the concentration of HCℓ in the sample chamber. Other gases do not cause modulation of the detector signal since they absorb the reference and measure beams equally. Thus, the Gas Filter Correlation System responds solely to HCℓ.

Options

15-001 — Particulate Filter

15-002 — Rack Mounts

Thermo Environmental Instruments Inc.

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Franklin, MA 02038

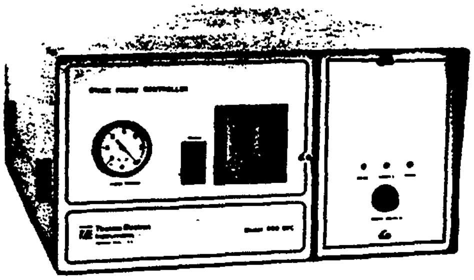
(508) 520-0430
Telex: 200205 THEMO UR

FAX: (508) 520-1460

Printed in U.S.A. — 9/90 SN

DILUTION SYSTEM

Model 200
SPC/DPC Probe Flow Controller



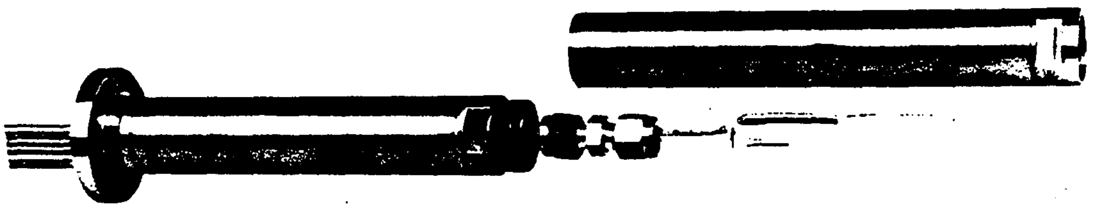
Thermo Environmental's Model 200 SPC Probe Flow Controller is an essential component of the Model 200 Extractive Continuous Emissions Monitoring System.

The Probe Flow Controller: controls the flow of dilution air to the probe; controls the flow of diluted sample to the analyzer enclosure; monitors the vacuum generated by the aspirator in the probe tip and controls the flow of calibration gases for a truly dynamic calibration. The Dual Probe Flow Controller, in addition to performing the above functions can be sequenced between two sampling streams to allow "time-sharing" of analyzers.

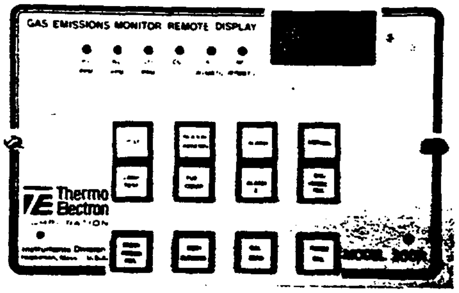
Model 200
In-Situ Sample Conditioning and Dilution Probe

Thermo Environmental's Model 200 is an extractive sampling system where sample conditioning is performed at the probe tip. Dry instrument air serves the triple function of extracting the sample, diluting it and transporting it under pressure to remote analyzers.

All probe parts exposed to the flue gases are constructed of Inconel 600, Hastelloy C-276, 304 stainless steel and Pyrex glass.



Model 200R
Remote Control and Digital Display



The microprocessor-based Model 200R is designed to function as a remote unit for a Continuous Emissions Monitoring System of Thermo Environmental manufacturer. The Model 200R automatically initiates system calibration; displays instantaneous values for pollutant and diluent gases; calculates pollutant emission rate in pounds/MBTU; provides 1 min, 1 hour and 3 hour averages of ppm and pounds/MBTU; allows adjustments for emission rate calculations and provides 4-20 ma output of all parameters to host data acquisition system.

APPENDIX D-1

OPERATING CONDITIONS FOR ALL PILOT TEST RUNS

APPENDIX D-1: PILOT TEST RUN DATA

Phase I Baseline:

Run No.		3A *	3B *	4A *	4B *	7A	8A	13A	14A
Run Date		1/22/92	1/22/92	1/23/92	1/23/92	1/29/92	1/30/92	2/14/92	2/19/92
Run Type		MSW	MSW	MSW	MSW	MSW	MSW	MSW	MSW
Oxygen Enrichment Zone									
% Oxygen									
Start Time		9:54	14:17	8:27	15:06	9:09	8:29	8:30	9:16
End Time		13:04	17:12	11:21	16:56	11:13	11:01	10:30	11:44
Duration	(min)	190	175	174	110	124	151	120	148
Underfire Air	(lb/hr)	2434	2458	2507	2409	2332	2448	2100	2397
Overfire Air	(lb/hr)	1114	1119	1037	618	1035	1086	901	1084
Oxygen	(lb/hr)								
Nozzle Atomizing Air	(lb/hr)								
Total Air+O2	(lb/hr)	3548	3577	3544	3027	3367	3534	3001	3481
MSW	(lb/hr)	702	690	758	754	602	668	539	579
Sludge Flow (wet)	(lb/hr)	0	0	0	0	0	0	0	0
Sludge Solids	(wt %)								
Dry Sludge/MSW	(wt %)								
Oxygen/Dry Sludge	(lb/lb)								
Ash Content	(%)	17.5	17.5	17.6	17.6	18.2	17.5	18.8	17.4
Combusted Material	(lb/hr)	579	569	625	621	492	551	438	478
Bottom Ash Carbon	(wt %)	0.64	0.11	2.24	1.88			0.40	0.66
Fly Ash Carbon	(wt %)	3.26	3.26	3.66	3.66			1.71	3.31
Flue Gas Flow	(lb/hr)	4726	4584	4602	4501	4375	4388	4021	4614
Flue Gas Moisture, meas'd	(%)	11.9	14.4	16.3	17.1	10.5	15.4	13.2	14.2
Flue Gas Moisture, adjusted	(%)	14.4				14.1			
O2, dry	(%)	10.7	12.2	12.6	11.8	10.0	8.8	9.6	10.5
O2, wet	(%)	9.2	10.4	10.5	9.8	8.6	7.4	8.3	9.0
1st Pass Temp	(F)	1748	1722	1717	1631	1513	1535	1561	1514
Flame Temp (Comb Zone)	(F)			2020	1770	2077			2210
Grate Temp	(F)	548	571	440	428	458	485	375	429

* Unsuccessful Test Runs: Runs 3A, 3B, 4A and 4B are not included in the data analysis because the heat and material balances for these runs indicated that the flue gas sampling probe was leaking during these baseline tests.

APPENDIX D-1: PILOT TEST RUN DATA

Phase I O2 Enriched MSW Incineration:

Run No.		7B	13B	7C	13C	14B	9A	14C
Run Date		1/29/92	2/14/92	1/29/92	2/14/92	2/19/92	2/10/92	2/19/92
Run Type		MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2
% Oxygen (OFA)							25.1	25.4
% Oxygen (Comb Zone UFA)		23.7	24.3	26.6	27.1	26.8		27.0
Start Time		11:43	11:29	16:45	14:09	12:44	15:05	15:53
End Time		14:30	13:29	19:43	15:59	15:13	18:06	18:09
Duration	(min)	167	120	178	110	149	181	136
Underfire Air	(lb/hr)	2306	2072	2288	2091	2268	2515	2190
Overfire Air	(lb/hr)	1041	911	1061	939	1070	806	763
Oxygen	(lb/hr)	83	83	166	166	166	50	216
Nozzle Atomizing Air	(lb/hr)							
Total Air+O2	(lb/hr)	3430	3066	3515	3196	3504	3371	3169
MSW	(lb/hr)	677	564	702	633	720	586	711
Sludge Flow (wet)	(lb/hr)							
Sludge Solids	(wt %)							
Dry Sludge/MSW	(wt %)							
Oxygen/Dry Sludge	(lb/lb)							
Ash Content	(%)	18.2	18.8	18.2	18.8	17.4	19.2	17.4
Combusted Material	(lb/hr)	554	458	574	514	595	473	587
Bottom Ash Carbon	(wt %)	1.56	0.33	0.23	0.54	0.54	0.35	0.83
Fly Ash Carbon	(wt %)	2.45	1.71	2.14	1.71	1.98	3.70	1.98
Flue Gas Flow	(lb/hr)	4412	4271	4499	4127	4495	4210	4460
Flue Gas Moisture, meas'd	(%)	14.1	12.7	13.7	12.9	16.9	11.1	16.6
Flue Gas Moisture, adjusted	(%)						15.3	
O2, dry	(%)	10.0	11.2	10.7	12.1	10.9	10.2	11.6
O2, wet	(%)	8.6	9.8	9.2	10.5	9.1	8.6	9.7
1st Pass Temp	(F)	1726	1565	1704	1584	1697	1553	1744
Flame Temp (Comb Zone)	(F)	2215		2253		2330	2037	2380
Grate Temp	(F)	644	568	762	765	695	438	759

APPENDIX D-1: PILOT TEST RUN DATA

Phase I O2 Enriched Coincineration (Sludge Pump/Sludge Extrusion Plate Feed System):

Run No.		8B *	10A *	10B *	11A *	12A *	12B *
Run Date		1/30/92	2/11/92	2/11/92	2/12/92	2/13/92	2/13/92
Run Type		MSW/Sldg	MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg/O2
% Oxygen (Burnout UFA)						24.3	24.1
% Oxygen (Comb Zone UFA)			24.6	24.6	24.6	25.4	26.0
Start Time		11:29	11:00	15:00	11:19	10:45	14:59
End Time		13:14	13:14	17:21	13:19	13:15	17:01
Duration	(min)	105	134	141	120	150	122
Underfire Air	(lb/hr)	2350	2283	2278	2257	2116	2069
Overfire Air	(lb/hr)	1040	1037	1021	1019	961	934
Oxygen	(lb/hr)		100	100	100	133	150
Nozzle Atomzing Air	(lb/hr)						
Total Air+O2	(lb/hr)	3390	3420	3399	3376	3210	3153
MSW	(lb/hr)	521	627	560	486	586	548
Sludge Flow (wet)	(lb/hr)	150	120	120	80	80	80
Sludge Solids	(wt %)	22.3		19.8		17.6	14.5
Dry Sludge/MSW	(wt %)	6.42		4.24		2.40	2.12
Oxygen/Dry Sludge	(lb/lb)	0		4.21		9.45	12.93
Ash Content	(%)	14.7	21.5	21.9	22.5	19.3	19.4
Combusted Material	(lb/hr)	572	586	531	439	537	506
Bottom Ash Carbon	(wt %)	0.48	2.86	1.42	0.93	1.52	1.38
Fly Ash Carbon	(wt %)	2.69	2.17	2.17	1.87	1.62	1.62
Flue Gas Flow	(lb/hr)	4203	4273	4218	4155	4193	4129
Flue Gas Moisture, meas'd	(%)		15.3	15.8	11.0	14.6	
Flue Gas Moisture, adjusted	(%)						
O2, dry	(%)	8.3	11.6	11.1	11.4	11.7	12.5
O2, wet	(%)	8.3	9.8	9.3	10.1	10.0	12.5
1st Pass Temp	(F)	1661	1475	1493	1542	1531	1499
Flame Temp (Comb Zone)	(F)	2040	2225	2125	2186	2114	2174
Grate Temp	(F)	350	156	398	283	396	449

* Unsuccessful Test Runs: Runs 8B, 10A, 10B, 11A, 12A and 12B were unsuccessful because sludge did not combust completely.
Incomplete sludge combustion can be recognized in this table by the increase in the ash content compared to Baseline.

APPENDIX D-1: PILOT TEST RUN DATA

Phase I O2 Enriched Coincineration (Sludge Pump/Sludge Atomization Nozzle Feed System):

Run No.		16A	16B	16C	17A *	17B	17C *
Run Date		2/26/92	2/26/92	2/26/92	2/27/92	2/27/92	2/27/92
Run Type		MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg	MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg/O2
% Oxygen (OFA)							23.1
% Oxygen (Comb Zone UFA)		24.9	26.5		24.9	25.0	24.4
Start Time		10:15	13:45	17:30	11:10	13:59	16:39
End Time		12:59	16:15	18:30	12:59	16:15	17:39
Duration	(min)	164	150	60	109	136	60
Underfire Air	(lb/hr)	2070	2010	2151	2063	2021	1988
Overfire Air	(lb/hr)	960	940	967	961	938	897
Oxygen	(lb/hr)	100	133		100	100	111
Nozzle Atomzing Air	(lb/hr)	240	240	240	240	240	240
Total Air	(lb/hr)	3370	3323	3358	3364	3299	3236
MSW	(lb/hr)	582	529	529	665	525	685
Sludge Flow (wet)	(lb/hr)	130	130	112	235	170	170
Sludge Solids	(wt %)	18.0	15.4	15.4	14.0	14.0	16.9
Dry Sludge/MSW	(wt %)	4.02	3.78	3.26	4.95	4.53	4.19
Oxygen/Dry Sludge	(lb/lb)	4.27	6.64	0.00	3.04	4.20	3.86
Ash Content	(%)	15.2 **	15.0 **	15.3 **	14.2 **	14.4 **	15.0 **
Combusted Material	(lb/hr)	604	560	543	772	595	727
Bottom Ash Carbon	(wt %)	0.33	0.91	0.28	0.76	0.68	0.53
Fly Ash Carbon	(wt %)	2.19	2.19	2.18	2.06	2.06	2.06
Flue Gas Flow	(lb/hr)	4504	4223	4172	4313	4137	4087
Flue Gas Moisture, meas'd	(%)	19.1	18.3	15.2		18.9	17.1
Flue Gas Moisture, adjusted	(%)			18.3	18.9		
O2, dry	(%)	10.3	10.6	9.9	9.3	10.7	10.9
O2, wet	(%)	8.3	8.7	8.1	7.5	8.7	9.0
1st Pass Temp	(F)	1480	1574	1494	1551	1491	1497
Flame Temp (Comb Zone)	(F)	1975	2313	2137	2243	2185	2102
Grate Temp	(F)	547	701	195	574	587	625

* Unsuccessful Test Runs: Runs 17A and 17C are considered unsuccessful because the closure of the energy balance for these runs was poor, as well as the fact that the sludge atomization nozzle was not atomizing properly due to erosion.

** Based on estimated ash contents of sludge (5.0 wt%) and MSW (17.5 wt%)

APPENDIX D-1: PILOT TEST RUN DATA

Phase II Baseline:

Run No.		20	21 *	22A	23A	24A
Run Date		9/2/92	9/3/92	9/4/92	9/14/92	9/15/92
Run Type		MSW	Wet MSW	MSW	MSW	MSW
Oxygen Enrichment Zone						
% Oxygen						
Start Time		17:06	13:00	10:34	9:30	9:29
End Time		19:34	15:50	11:04	12:00	11:31
Duration	(min)	148	170	30	150	122
Underfire Air	(lb/hr)	2306	1987	2313	2113	2219
Overfire Air	(lb/hr)	1164	1019	1154	1070	1118
Oxygen	(lb/hr)	0	0	0	0	0
Nozzle Atomzing Air	(lb/hr)	0	0	0	0	0
Total Air+O2	(lb/hr)	3470	3006	3467	3183	3337
MSW	(lb/hr)	575	529	636	629	649
Sludge Flow (wet)	(lb/hr)	0	0	0	0	0
Sludge Solids	(wt %)	0	0	0	0	0
Dry Sludge/MSW	(wt %)					
Oxygen/Dry Sludge	(lb/lb)					
Ash Content	(wt %)	17.2	20.8	20.8	16.0	20.4
Combusted Material	(lb/hr)	476	419	504	528	517
Bottom Ash Carbon (1)	(wt %)	BDL	0.9		0.3	
Fly Ash Carbon	(wt %)	5.5	2.7		1.1	0.8
Flue Gas Flow	(lb/hr)	4712	4561	4740	4513	4692
Flue Gas Moisture, meas'd	(%)		15		13.9	
Flue Gas Moisture, adjusted	(%)	14		14	15	15
O2, dry	(%)	10.0	11.2	9.0	9.8	9.7
O2, wet	(%)	8.6	9.5	7.7	8.3	8.2
1st Pass Temperature	(F)	1601	1340	1560	1669	1602
Flame Temp (Comb Zone)	(F)	2165	1893	2105	2023	2024
Grate Temperature	(F)	339	378	436	377	356

1 BDL = Below Detection Limit of 0.1%

* Unsuccessful Test Run: Run 21 is considered unsuccessful because the closure of the energy balance for this run was poor.

APPENDIX D-1: PILOT TEST RUN DATA

Phase II Coincineration without Oxygen Enrichment:

Run No.		22B	26B
Run Date		9/4/92	9/17/92
Run Type		MSW/Sldg	MSW/Sldg
Oxygen Enrichment Zone			
% Oxygen			
Start Time		11:10	11:05
End Time		12:00	14:00
Duration	(min)	50	175
Underfire Air	(lb/hr)	2100	1924
Overfire Air	(lb/hr)	1070	960
Oxygen	(lb/hr)	0	0
Nozzle Atomzing Air	(lb/hr)	305	392
Total Air+O2	(lb/hr)	3475	3276
MSW	(lb/hr)	616	552
Sludge Flow (wet)	(lb/hr)	235	370
Sludge Solids	(wt %)	13.4	16.8
Dry Sludge/MSW	(wt %)	5.11	11.26
Oxygen/Dry Sludge	(lb/lb)		
Ash Content	(wt %)	16.2	12.6
Combusted Material	(lb/hr)	713	806
Bottom Ash Carbon	(wt %)	0.2	0.3
Fly Ash Carbon	(wt %)	1.4	1.0
Flue Gas Flow	(lb/hr)	4827	4936
Flue Gas Moisture, meas'd	(%)		20.6
Flue Gas Moisture, adjusted	(%)	20	21.5
O2, dry	(%)	7.3	8.6
O2, wet	(%)	5.8	6.8
1st Pass Temperature	(F)	1605	1608
Flame Temp (Comb Zone)	(F)	2080	2063
Grate Temperature	(F)	398	172

APPENDIX D-1: PILOT TEST RUN DATA

Phase II O2 Enriched Coincineration (Sludge Pump/Sludge Atomization Nozzle Feed System):

Run No.		22C	23B	23C	24B	24C	25B	25C
Run Date		9/4/92	9/14/92	9/14/92	9/15/92	9/15/92	9/16/92	9/16/92
Run Type		MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg/O2	MSW/Sldg/O2
Oxygen Enrichment		OFA	OFA	OFA	OFA	OFA	Sludge Gun	Sludge Gun
% Oxygen		36.3	39.1	34.1	43.7	41.2		
Start Time		14:16	12:24	16:00	11:35	14:34	9:50	14:00
End Time		16:05	14:44	17:30	14:00	16:51	12:16	16:30
Duration	(min)	109	140	90	145	137	146	150
Underfire Air	(lb/hr)	1834	1791	1783	1774	1809	1764	1697
Overfire Air	(lb/hr)	785	739	783	676	717	890	842
Oxygen	(lb/hr)	210	244	171	302	272	272	328
Nozzle Atomzing Air	(lb/hr)	305	392	392	392	392	0	0
Total Air+O2	(lb/hr)	3134	3166	3129	3144	3190	2926	2867
MSW	(lb/hr)	610	697	641	583	591	752	750
Sludge Flow (wet)	(lb/hr)	235	370	370	370	490	370	370
Sludge Solids	(wt %)	15.1	15.4	15.0	15.0	13.3	14.6	13.4
Dry Sludge/MSW	(wt %)	5.82	8.18	8.66	9.52	11.03	7.18	6.61
Oxygen/Dry Sludge	(lb/lb)	5.92	4.28	3.08	5.44	4.17	5.04	6.62
Ash Content	(wt %)	16.3	12.1	11.7	14.1	12.8	16.8	17.0
Combusted Material	(lb/hr)	707	938	893	819	943	934	930
Bottom Ash Carbon (1)	(wt %)	BDL	0.3	BDL	0.3	0.2	BDL	0.4
Fly Ash Carbon	(wt %)	1.0	1.1	1.1	0.8	0.8	0.7	0.7
Flue Gas Flow	(lb/hr)	4774	4815	4803	4758	4702	4742	4605
Flue Gas Moisture, meas'd	(%)	19.2	20.8	26.6	19.2	22.2	25.1	22.9
Flue Gas Moisture, adjusted	(%)	20.5	26		25	27	26.5	26.5
O2, dry	(%)	10.0	8.4	7.6	10.8	10.9	10.4	12.2
O2, wet	(%)	8.0	6.2	5.6	8.1	8.0	7.6	9.0
1st Pass Temperature	(F)	1683	1759	1767	1725	1671	1684	1640
Flame Temp (Comb Zone)	(F)	2150	1958	1966	2064	1955	2225	2215
Grate Temperature	(F)	288	617	526	397	459	673	578

1 BDL = Below Detection Limit of 0.1%

APPENDIX D-2

FLUE GAS EMISSIONS FOR ALL PILOT TEST RUNS

APPENDIX D-2: PILOT TEST EMISSIONS DATA

Phase I Baseline:

Run No.		3A	3B	4A	4B	7A	8A	13A	14A	Averages
Run Date		1/22/92	1/22/92	1/23/92	1/23/92	1/29/92	1/30/92	2/14/92	2/19/92	(7A, 8A, 13A
Run Type		MSW	MSW	MSW	MSW	MSW	MSW	MSW	MSW	& 14A)
% Oxygen (OFA)										
% Oxygen (Burnout UFA)										
% Oxygen (Comb Zone UFA)										
Start Time		9:54	14:17	8:27	15:06	9:09	8:29	8:30	9:16	
End Time		13:04	17:12	11:21	16:56	11:13	11:01	10:30	11:44	
Duration	(min)	190	175	174	110	124	151	120	148	
MSW	(lb/hr)	702	690	758	754	602	668	539	579	
Sludge	(lb/hr)									
Oxygen	(lb/hr)									
O2, average	%	10.7	12.2	12.6	11.8	10.0	8.8	9.6	10.5	9.7
std deviation	%	2.1	1.6	1.6	2.3	2.1	3.2	2.2	1.9	
CO2, average	%	9.0	7.5	6.6	7.5	9.4	10.6	10.1	8.9	9.8
std deviation	%	2.0	1.5	2.1	2.0	2.0	3.0	2.0	1.7	
CO, avg @ 7% O2 (1)	ppm	219	106	167	389	151	232	73	151	152
std deviation	ppm	213	35	226	541	169	380	78	243	
NOx, avg @ 7% O2	ppm	208	212	191	175	232	192	256	324	251
std deviation	ppm	39	29	48	26	13	52	19	24	
SO2, avg @ 7% O2	ppm	153	35	62	81	76	99	243	210	157
std deviation	ppm	146	51	125	100	14	34	42	28	
HC, avg @ 7% O2	ppm	16.3	8.6	18.5	29.3	2.3	9.0	5.2	2.4	4.7
std deviation	ppm	32	15	31.1	47.8	2.5	12.0	17.4	8.5	
HCl, avg @ 7% O2	ppm	183	394	550	503	344	344	252	274	304
std deviation	ppm	298	168	245	135	35	28	34	49	

Notes -

1 CO data corrected, > 800 ppm (as measured) was deleted due to excursion.

APPENDIX D-2: PILOT TEST EMISSIONS DATA

Phase I O2 Enriched MSW Incineration:

Run No.		7B	13B	7C	13C	14B	9A	14C	Averages (7B & 13B)	Averages (7C, 13C & 14B)
Run Date		1/29/92	2/14/92	1/29/92	2/14/92	2/19/92	2/10/92	2/19/92		
Run Type		MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2		
% Oxygen (OFA)							25.1	25.4		
% Oxygen (Comb Zone UFA)		23.7	24.3	26.6	27.1	26.8		27.0		
Start Time		11:43	11:29	16:45	14:09	12:44	15:05	15:53		
End Time		14:30	13:29	19:43	15:59	15:13	18:06	18:09		
Duration	(min)	167	120	178	110	149	181	136		
MSW	(lb/hr)	677	564	702	633	720	586	711		
Sludge	(lb/hr)									
Oxygen	(lb/hr)	83	83	166	166	166	50	216		
O2, average	%	10.0	11.2	10.7	12.1	10.9	10.2	11.6	10.6	11.2
std deviation	%	1.9	2.2	2.5	2.0	2.2	1.8	2.7		
CO2, average	%	10.7	9.8	11.7	10.4	10.9	10.0	11.3	10.3	11.0
std deviation	%	2.0	2.1	2.4	2.0	2.1	1.7	2.6		
CO, avg @ 7% O2 (1)	ppm	65	136	108	110	116	104	103	101	111
std deviation	ppm	36	159	102	80	166	102	138		
NOx, avg @ 7% O2	ppm	275	295	228	319	436	262	334	285	328
std deviation	ppm	26	21	26	28	52	25	69		
SO2, avg @ 7% O2	ppm	121	237	112	283	301	109	308	179	232
std deviation	ppm	29	32	103	49	133	28	122		
HC, avg @ 7% O2	ppm	3.8	2.1	3.4	12.7	7.0	0.6	3.7	3.0	7.7
std deviation	ppm	11.7	0.8	10.2	14.3	34.7	0.8	24.0		
HCl, avg @ 7% O2	ppm	421	188	426	215	367	383	438	305	336
std deviation	ppm	160	39	197	37	84	149	116		

Notes -

1 CO data corrected, > 800 ppm (as measured) was deleted due to excursion.

APPENDIX D-2: PILOT TEST EMISSIONS DATA

Phase I O2 Enriched Coincineration (Sludge Pump/Sludge Extrusion Plate Feed System):

Run No.		8B	10A	10B	11A	12A	12B	Averages
Run Date		1/30/92	2/11/92	2/11/92	2/12/92	2/13/92	2/13/92	
Run Type		MSW/S	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	
% Oxygen (OFA)								
% Oxygen (Burnout UFA)						24.3	24.1	
% Oxygen (Comb Zone UFA)			24.6	24.6	24.6	25.4	26.0	
Start Time		11:29	11:00	15:00	11:19	10:45	14:59	
End Time		13:14	13:14	17:21	13:19	13:15	17:01	
Duration	(min)	105	134	141	120	150	122	
MSW	(lb/hr)	521	627	560	486	586	548	
Sludge	(lb/hr)	150	120	120	80	80	80	
Oxygen	(lb/hr)		100	100	100	133	150	
O2, average	%	8.3	11.6	11.1	11.4	11.7	12.5	11.1
std deviation	%	1.9	1.9	2.5	1.5	2.6	2.2	
CO2, average	%	10.9	9.8	10.2	10.2	10.2	9.8	10.2
std deviation	%	1.8	1.7	2.4	1.4	2.6	2.2	
CO, avg @ 7% O2 (1)	ppm	95	203	252	96	201	242	181.5
std deviation	ppm	85	277	399	92	236	447	
NOx, avg @ 7% O2	ppm	238	289	311	260	313	347	293.0
std deviation	ppm	30	21	37	12	32	45	
SO2, avg @ 7% O2	ppm	93	66	33	167	257	307	153.8
std deviation	ppm	32	49	36	25	71	42	
HC, avg @ 7% O2	ppm	4.1	2.2	15.5	1.1	2.8	3.6	4.9
std deviation	ppm	4.9	3.6	68.0	0.9	6.6	7.5	
HCl, avg @ 7% O2	ppm	343	395	489	148	834	772	496.8
std deviation	ppm	57	146	175	35	311	293	

Notes -
1 CO data corrected, > 800 ppm (as measured) was deleted due to excursion.

APPENDIX D-2: PILOT TEST EMISSIONS DATA

Phase I O_2 Enriched Coincineration (Sludge Pump/Sludge Atomization Nozzle Feed System):

Run No.		16A	16B	16C	17A	17B	17C	Averages
Run Date		2/26/92	2/26/92	2/26/92	2/27/92	2/27/92	2/27/92	(16A,16B,
Run Type		MSW/S/O2	MSW/S/O2	MSW/S	MSW/S/O2	MSW/S/O2	MSW/S/O2	17B)
% Oxygen (OFA)							23.1	
% Oxygen (Burnout UFA)								
% Oxygen (Comb Zone UFA)		24.9	26.5		24.9	25.0	24.4	
Start Time		10:15	13:45	17:30	11:10	13:59	16:39	
End Time		12:59	16:15	18:30	12:59	16:15	17:39	
Duration	(min)	164	150	60	109	136	60	
MSW	(lb/hr)	582	529	529	665	525	685	
Sludge	(lb/hr)	130	130	112	235	170	170	
Oxygen	(lb/hr)	100	133		100	100	111	
O_2, average	%	10.3	10.6	9.9	9.3	10.7	10.9	**10.5**
std deviation	%	2.7	2.1	1.0	1.6	1.5	1.6	
CO_2, average	%	10.6	11.0	9.4	11.6	10.4	10.4	**10.7**
std deviation	%	2.6	2.0	0.9	1.5	1.4	1.6	
CO, avg @ 7% O_2 (1)	ppm	269	170	109	158	265	235	**235**
std deviation	ppm	281	222	87	170	311	314	
NO_x, avg @ 7% O_2	ppm	220	282	214	253	237	253	**246**
std deviation	ppm	41	24	16	19	20	24	
SO_2, avg @ 7% O_2	ppm	202	204	148	172	201	199	**202**
std deviation	ppm	53	41	12	21	27	28	
HC, avg @ 7% O_2	ppm	25.4	9.8	3.1	7.9	12.1	14.4	**15.8**
std deviation	ppm	29.4	12.8	1.1	3.8	11.0	9.0	
HCl, avg @ 7% O_2	ppm	272	333	285	267	393	351	**333**
std deviation	ppm	98	71	26	100	69	34	

Notes -

1 CO data corrected, > 800 ppm (as measured) was deleted due to excursion.

APPENDIX D-2: PILOT TEST EMISSIONS DATA

Phase II Baseline:

Run No.		20	21	22A	23A	24A	Averages
Run Date		9/2/92	9/3/92	9/4/92	9/14/92	9/15/92	(w/o Run 21)
Run Type		MSW	Wet MSW	MSW	MSW	MSW	
Oxygen Enrichment Zone							
% Oxygen							
Start Time		17:06	13:00	10:34	9:30	9:29	
End Time		19:34	15:50	11:04	12:00	11:31	
Duration	(min)	148	170	30	150	122	
MSW	(lb/hr)	575	529	636	629	649	
Sludge	(lb/hr)	0	0	0	0	0	
Oxygen	(lb/hr)	0	0	0	0	0	
O2, average	%	10.0	11.2	9.0	9.8	9.7	9.6
std deviation	%	2.8	2.3	1.8	2.1	2.0	
CO2, average	%	9.4	8.4	10.4	9.3	9.6	9.7
std deviation	%	2.5	2.1	1.7	2.1	1.9	
CO, avg @ 7% O2 (1)	ppm	176	789	68	67	105	104
std deviation	ppm	242	1573	18	32	119	
NOx, avg @ 7% O2	ppm	204	224	218	202	221	211
std deviation	ppm	18	13	7	15	10	
SO2, avg @ 7% O2	ppm	153	117	112	69	77	103
std deviation	ppm	124	56	17	37	19	
HC, avg @ 7% O2	ppm	-4	52.6	11.9	2.0	2.5	3.1
std deviation	ppm	3.7	150.4	1.1	2.4	2.9	

Notes -

1 CO data corrected, > 800 ppm (as measured) was deleted due to excursion.

APPENDIX D-2: PILOT TEST EMISSIONS DATA

Phase II Coincineration without Oxygen Enrichment:

Run No.		22B	26B	Averages
Run Date		9/4/92	9/17/92	
Run Type		MSW/S	MSW/S	
Oxygen Enrichment Zone				
% Oxygen				
Start Time		11:10	11:05	
End Time		12:00	14:00	
Duration	(min)	50	175	
MSW	(lb/hr)	616	552	
Sludge	(lb/hr)	235	370	
Oxygen	(lb/hr)	0	0	
O2, average	%	7.3	8.6	8.0
std deviation	%	2.4	1.2	
CO2, average	%	11.8	10.6	11.2
std deviation	%	2.2	1.2	
CO, avg @ 7% O2 (1)	ppm	186	106	146.0
std deviation	ppm	168	71	
NOx, avg @ 7% O2	ppm	160	164	162.0
std deviation	ppm	15	67	
SO2, avg @ 7% O2	ppm	177	96	136.5
std deviation	ppm	32	44	
HC, avg @ 7% O2	ppm	11.9	8.7	10.3
std deviation	ppm	3.0	10.7	

Notes -
1 CO data corrected, > 800 ppm (as measured) was deleted due to excursion.

APPENDIX D-2: PILOT TEST EMISSIONS DATA

Phase II O2 Enriched Coincineration (Sludge Pump/Sludge Atomization Nozzle Feed System):

Run No.		22C	23B	23C	24B	24C	25B	25C	Averages	Averages
Run Date		9/4/92	9/14/92	9/14/92	9/15/92	9/15/92	9/16/92	9/16/92		
Run Type		MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2		
Oxygen Enrichment Zone		OFA	OFA	OFA	OFA	OFA	Sludge Gun	Sludge Gun	OFA	Sludge Gun
% Oxygen (2)		36.3	39.1	34.1	43.7	41.2				
Start Time		14:16	12:24	16:00	11:35	14:34	9:50	14:00		
End Time		16:05	14:44	17:30	14:00	16:51	12:16	16:30		
Duration	(min)	109	140	90	145	137	146	150		
MSW	(lb/hr)	610	697	641	583	591	752	750		
Sludge	(lb/hr)	235	370	370	370	490	370	370		
Oxygen	(lb/hr)	305	244	171	302	272	272	328		
O2, average	%	10.0	8.4	7.6	10.8	10.9	10.4	12.2	9.5	11.3
std deviation	%	1.5	2.1	1.7	1.4	2.3	2.0	1.3		
CO2, average	%	12.3	14.6	14.0	13.3	12.7	13.1	13.0	13.4	13.1
std deviation	%	1.5	2.0	1.6	1.4	2.3	1.9	1.3		
CO, avg @ 7% O2 (1)	ppm	77	65	56	80	136	91	150	83	121
std deviation	ppm	27	19	14	28	111	56	167		
NOx, avg @ 7% O2	ppm	303	259	235	341	278	342	367	283	355
std deviation	ppm	36	25	27	27	45	48	60		
SO2, avg @ 7% O2	ppm	195	247	179	170	216	141	149	201	145
std deviation	ppm	43	75	28	27	72	36	82		
HC, avg @ 7% O2	ppm	7.2	2.7	2.5	5.3	6.5	2.0	6.1	4.8	4.1
std deviation	ppm	0.9	0.7	1.5	1.3	1.6	0.8	3.5		

Notes -

1 CO data corrected, > 800 ppm (as measured) was deleted due to excursion.

2 Sludge Gun atomization air is not included in OFA flow.

APPENDIX D-3

BOTTOM ASH AND FLY ASH ANALYSIS FOR ALL PILOT TEST RUNS

APPENDIX D-3: BOTTOM ASH (BA)/FLY ASH (FA) ANALYSIS RESULTS (1)

Phase I Baseline:

PARAMETER		Det Limit	Method Ref (2)	BA-3A	BA-3B	BA-4A	BA-4B	BA-13A	BA-14A		Averages
											(13A,14A)
Arsenic as As	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Barium as Ba	ppm	25	6010	520	750	1,200	2,100	1,600	55		828
Cadmium as Cd	ppm	2.5	6010	BDL	3.9	BDL	6.4	4.9	5.0		5.0
Chromium as Cr	ppm	2.5	6010	39	53	42	63	82	76		79
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Lead as Pb	ppm	50	6010	150	220	120	420	280	760		520
Selenium as Se	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Chloride (water extractable)	ppm	150	4500B	720	400	120	6,100	2,100	2,400		2,250
Sulfate (water extractable)	ppm	150	9038	510	810	400	490	3,100	4,200		3,650
Total Organic Carbon	%	0.1		0.64	0.11	2.24	1.88	0.4	0.66		0.53

				FA-3 A/B		FA-4 A/B		FA-13	FA-14A		Averages
											(13A,14A)
Arsenic as As	ppm	10	6010	BDL		BDL		BDL	BDL		BDL
Barium as Ba	ppm	25	6010	870		850		14	12		13
Cadmium as Cd	ppm	25	6010	840		900		1,000	1,200		1,100
Chromium as Cr	ppm	25	6010	26		130		200	190		195
Mercury as Hg	ppm	0.1	7471	BDL		BDL		BDL	BDL		BDL
Lead as Pb	ppm	50	6010	20,000		21,000		4,000	11,000		7,500
Selenium as Se	ppm	10	6010	BDL		BDL		BDL	BDL		BDL
Silver as Ag	ppm	2.5	6010	BDL		BDL		BDL	BDL		BDL
Chloride (water extractable)	ppm	150	4500B	140,000		160,000		*2900 (3)*	130,000		130,000
Sulfate (water extractable)	ppm	1500	9038	28,000		32,000		43,000	44,000		43,500
Total Organic Carbon	%	0.1		3.26		3.66		1.71	3.31		2.51

1 BDL = Below Detection Limit

2 Test Methods for Evaluating Solid Waste, SW-846, 3rd ed., 1986 and Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989.

3 Unreasonable data point based upon other data, not included in averages.

APPENDIX D-3: BOTTOM ASH (BA) /FLY ASH (FA) ANALYSIS RESULTS (1)

Phase I O2 Enriched MSW Incineration:

PARAMETER		Det Limit	Method Ref (2)	BA-7B	BA-7C	BA-9A	BA-13B	BA-13C	BA-14B	BA-14C	Averages
Arsenic as As	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Barium as Ba	ppm	25	6010	510	920	700	560	490	940	490	659
Cadmium as Cd	ppm	2.5	6010	BDL	3.8	6.7	3.6	3.3	3.3	8.6	
Chromium as Cr	ppm	2.5	6010	34	55	86	64	70	80	110	71
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Lead as Pb	ppm	50	6010	450	230	280	2,400	1,600	750	1,800	1,073
Selenium as Se	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Chloride (water extractable)	ppm	150	4500B	2,500	1,800	410	1,500	870	1,100	2,200	1,483
Sulfate (water extractable)	ppm	150	9038	750	200	410	3,700	2,200	1,700	1,800	1,537
Total Organic Carbon	%	0.1		1.56	0.23	0.35	0.33	0.54	0.54	0.83	0.63
				FA-7B	FA-7C	FA-9	FA-13		FA-14 B/C		Averages
Arsenic as As	ppm	10	6010	BDL	BDL	BDL	BDL		BDL		BDL
Barium as Ba	ppm	25	6010	820	710	690	14		460		539
Cadmium as Cd	ppm	25	6010	860	1,200	1,300	1,000		820		1,036
Chromium as Cr	ppm	25	6010	110	110	140	200		130		138
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL	BDL		BDL		BDL
Lead as Pb	ppm	50	6010	20,000	21,000	24,000	4,000		15,000		16,800
Selenium as Se	ppm	10	6010	BDL	BDL	BDL	BDL		BDL		BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL	BDL		BDL		BDL
Chloride (water extractable)	ppm	150	4500B	150,000	170,000	180,000	*2900 (3)*		170,000		167,500
Sulfate (water extractable)	ppm	1500	9038	26,000	27,000	36,000	43,000		27,000		31,800
Total Organic Carbon	%	0.1		2.45	2.14	3.7	1.71		1.98		2.40

1 BDL = Below Detection Limit

2 Test Methods for Evaluating Solid Waste, SW-846, 3rd ed., 1986 and Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989.

3 Unreasonable data point based upon other data, not included in averages.

APPENDIX D-3: BOTTOM ASH (BA) /FLY ASH (FA) ANALYSIS RESULTS (1)

Phase I O2 Enriched Coincineration (Sludge Pump/Sludge Extrusion Plate Feed System): (3)

PARAMETER		Det Limit	Method Ref (2)	BA-8B	BA-10A	BA-10B	BA-11A	BA-12A	BA-12B		Averages
Arsenic as As	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Barium as Ba	ppm	25	6010	1,100	450	900	1,000	460	1,000		818
Cadmium as Cd	ppm	2.5	6010	4.8	7.4	12	5.8	10	9.7		8
Chromium as Cr	ppm	2.5	6010	64	81	73	58	100	100		79
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Lead as Pb	ppm	50	6010	280	530	700	590	760	560		570
Selenium as Se	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Chloride (water extractable)	ppm	150	4500B	2,300	2,600	1,100	1,600	2,300	3,300		2,200
Sulfate (water extractable)	ppm	150	9038	30	1,700	670	1,700	1,700	1,800		1,267
Total Organic Carbon	%	0.1		0.48	2.86	1.42	0.93	1.52	1.38		1.43
				FA-8B	FA-10		FA-11	FA-12			Averages
Arsenic as As	ppm	10	6010	BDL	BDL		BDL	BDL			BDL
Barium as Ba	ppm	25	6010	630	210		270	72			296
Cadmium as Cd	ppm	25	6010	940	880		920	750			873
Chromium as Cr	ppm	25	6010	120	150		150	200			155
Mercury as Hg	ppm	0.1	7471	BDL	BDL		BDL	BDL			BDL
Lead as Pb	ppm	50	6010	14,000	18,000		18,000	13,000			15,750
Selenium as Se	ppm	10	6010	BDL	BDL		BDL	BDL			BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL		BDL	BDL			BDL
Chloride (water extractable)	ppm	150	4500B	160,000	120,000		130,000	120,000			132,500
Sulfate (water extractable)	ppm	1500	9038	30,000	30,000		46,000	44,000			37,500
Total Organic Carbon	%	0.1		2.69	2.17		1.87	1.62			2.09

1 BDL = Below Detection Limit

2 Test Methods for Evaluating Solid Waste, SW-846, 3rd ed., 1986 and Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989.

3 Bottom ash samples collected and anlayzed for these coincineration runs are not truly representative of the bottom ash since there was unburned sludge contained in the ash that was not included in the sample. Samples of unburned sludge were analyzed separately. Total organic carbon in the unburned sludge samples ranged from 19% to 32%, dry weight.

APPENDIX D-3: BOTTOM ASH (BA) /FLY ASH (FA) ANALYSIS RESULTS (1)

Phase I O2 Enriched Coincineration (Sludge Pump/Sludge Atomization Nozzle Feed System):

PARAMETER		Det Limit	Method Ref (2)	BA-16A	BA-16B	BA-16C	BA-17A	BA-17B	BA-17C		Averages
											16A/B,17B
Arsenic as As	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Barium as Ba	ppm	25	6010	630	590	590	750	910	950		710
Cadmium as Cd	ppm	2.5	6010	11.0	9.3	6.9	4.3	5.3	10.0		8.5
Chromium as Cr	ppm	2.5	6010	76	98	98	70	77	90		84
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Lead as Pb	ppm	50	6010	3,700	690	460	610	580	350		1,657
Selenium as Se	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL	BDL	BDL	BDL		BDL
Chloride (water extractable)	ppm	150	4500B	2,400	2,200	760	1,800	1,700	2,800		2,100
Sulfate (water extractable)	ppm	150	9038	2,000	2,800	2,300	1,600	1,100	2,300		1,967
Total Organic Carbon	%	0.1		0.33	0.91	0.28	0.76	0.68	0.53		0.64
				FA-16A/B		FA-16C	FA-17				Averages
											16A/B,17B
Arsenic as As	ppm	10	6010	BDL		BDL	BDL				BDL
Barium as Ba	ppm	25	6010	580		560	410				495
Cadmium as Cd	ppm	25	6010	860		850	690				775
Chromium as Cr	ppm	25	6010	530		390	230				380
Mercury as Hg	ppm	0.1	7471	BDL		BDL	BDL				BDL
Lead as Pb	ppm	50	6010	17,000		16,000	15,000				16,000
Selenium as Se	ppm	10	6010	BDL		BDL	BDL				BDL
Silver as Ag	ppm	2.5	6010	BDL		BDL	BDL				BDL
Chloride (water extractable)	ppm	150	4500B	84,000		100,000	130,000				107,000
Sulfate (water extractable)	ppm	1500	9038	13,000		19,000	22,000				17,500
Total Organic Carbon	%	0.1		2.19		2.18	2.06				2.13

1 BDL = Below Detection Limit

2 Test Methods for Evaluating Solid Waste, SW-846, 3rd ed., 1986 and Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989.

APPENDIX D-3: BOTTOM ASH (BA) /FLY ASH (FA) ANALYSIS RESULTS (1)

Phase II Baseline:

PARAMETER		Det Limit	Method Ref (2)	BA-20	BA-21	BA-22A	BA-23A	BA-24A			Averages
											(w/o Run 21)
Arsenic as As	ppm	10	6010	BDL	BDL		BDL				BDL
Barium as Ba	ppm	25	6010	440	260		430				435
Cadmium as Cd	ppm	2.5	6010	3.6	3.4		3.8				3.7
Chromium as Cr	ppm	2.5	6010	58	35		46				52
Mercury as Hg	ppm	0.1	7471	BDL	BDL		BDL				BDL
Lead as Pb	ppm	50	6010	1100	440		1200				1,150
Selenium as Se	ppm	10	6010	BDL	BDL		BDL				BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL		BDL				BDL
Chloride (water extractable)	ppm	150	4500B	2,000	2,500		1,300				1,650
Sulfate (water extractable)	ppm	150	9038	2,600	1,600		1,800				2,200
Total Organic Carbon	%	0.1		BDL	0.88		0.28				< 0.19
				FA-20	FA-21	FA-22A	FA-23	FA-24			Averages
											(w/o Run 21)
Arsenic as As	ppm	10	6010	130	160		110	190			143
Barium as Ba	ppm	25	6010	340	480		350	100			263
Cadmium as Cd	ppm	25	6010	270	210		290	410			323
Chromium as Cr	ppm	25	6010	90	110		110	190			130
Mercury as Hg	ppm	0.1	7471	0.56	0.45		0.14	BDL			< 0.27
Lead as Pb	ppm	50	6010	7,300	7,200		6,700	9,000			7,667
Selenium as Se	ppm	10	6010	BDL	BDL		BDL	BDL			BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL		BDL	BDL			BDL
Chloride (water extractable)	ppm	150	4500B	3,500	30,000		34,000	25,000			20,833
Sulfate (water extractable)	ppm	1500	9038	22,000	20,000		37,000	38,000			32,333
Total Organic Carbon	%	0.1		5.48	2.67		1.14	0.84			2.49

1 BDL = Below Detection Limit

2 Test Methods for Evaluating Solid Waste, SW-846, 3rd ed., 1986 and Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989.

APPENDIX D-3: BOTTOM ASH (BA) /FLY ASH (FA) ANALYSIS RESULTS (1)

Phase II Coincineration without O2 Enrichment:

PARAMETER		Det Limit	Method Ref (2)	BA-22B	BA-26B						Averages
Arsenic as As	ppm	10	6010	BDL	BDL						BDL
Barium as Ba	ppm	25	6010	450	500						475
Cadmium as Cd	ppm	2.5	6010	3.4	3.9						3.7
Chromium as Cr	ppm	2.5	6010	39	66						53
Mercury as Hg	ppm	0.1	7471	BDL	BDL						BDL
Lead as Pb	ppm	50	6010	290	650						470
Selenium as Se	ppm	10	6010	BDL	BDL						BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL						BDL
Chloride (water extractable)	ppm	150	4500B	2,700	870						1,785
Sulfate (water extractable)	ppm	150	9038	3,500	1,300						2,400
Total Organic Carbon	%	0.1		0.21	0.3						0.26
				FA-22B	FA-26B						Averages
Arsenic as As	ppm	10	6010	120	130						125
Barium as Ba	ppm	25	6010	450	310						380
Cadmium as Cd	ppm	25	6010	150	260						205
Chromium as Cr	ppm	25	6010	97	140						119
Mercury as Hg	ppm	0.1	7471	0.38	0.38						0.38
Lead as Pb	ppm	50	6010	5,700	7,100						6,400
Selenium as Se	ppm	10	6010	BDL	BDL						BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL						BDL
Chloride (water extractable)	ppm	150	4500B	33,000	21,000						27,000
Sulfate (water extractable)	ppm	1500	9038	22,000	29,000						25,500
Total Organic Carbon	%	0.1		1.4	1.03						1.22

1 BDL = Below Detection Limit

2 Test Methods for Evaluating Solid Waste, SW-846, 3rd ed., 1986 and Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989.

APPENDIX D-3: BOTTOM ASH (BA) /FLY ASH (FA) ANALYSIS RESULTS (1)

Phase II O2 Enriched Coincineration (Sludge Pump/Sludge Extrusion Plate Feed System):

PARAMETER		Det Limit	Method Ref (2)	BA-22C	BA-23B	BA-23C	BA-24B	BA-24C	BA-25B	BA-25C	Averages
Arsenic as As	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Barium as Ba	ppm	25	6010	300	460	480	560	440	290	600	447
Cadmium as Cd	ppm	2.5	6010	3.5	3.4	21	4.5	4.8	2.5	3.6	6.2
Chromium as Cr	ppm	2.5	6010	37	55	46	66	57	40	68	53
Mercury as Hg	ppm	0.1	7471	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Lead as Pb	ppm	50	6010	370	440	530	390	490	370	490	440
Selenium as Se	ppm	10	6010	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Chloride (water extractable)	ppm	150	4500B	1,800	2,600	1,200	2,300	1,600	1,900	1600	1,857
Sulfate (water extractable)	ppm	150	9038	1,100	1,000	2,200	2,100	1,400	910	2200	1,559
Total Organic Carbon	%	0.1		BDL	0.33	BDL	0.26	0.23	BDL	0.4	< 0.22
				FA-22C	FA-23		FA-24		FA-25B	FA-25C	Averages
Arsenic as As	ppm	10	6010	120	110		190		180	160	152
Barium as Ba	ppm	25	6010	200	350		100		340	380	274
Cadmium as Cd	ppm	25	6010	150	290		410		370	280	300
Chromium as Cr	ppm	25	6010	120	110		190		180	190	158
Mercury as Hg	ppm	0.1	7471	0.5	0.14		< 0.1		0.15	0.25	0.26
Lead as Pb	ppm	50	6010	5,200	6,700		9,000		11,000	8,700	8,120
Selenium as Se	ppm	10	6010	BDL	BDL		BDL		BDL	BDL	BDL
Silver as Ag	ppm	2.5	6010	BDL	BDL		BDL		BDL	BDL	BDL
Chloride (water extractable)	ppm	150	4500B	19,000	34,000		25,000		26,000	21,000	25,000
Sulfate (water extractable)	ppm	1500	9038	24,000	37,000		38,000		45,000	34,000	35,600
Total Organic Carbon	%	0.1		1.01	1.14		0.84		0.72	0.73	0.89

1 BDL = Below Detection Limit

2 Test Methods for Evaluating Solid Waste, SW-846, 3rd ed., 1986 and Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989.

APPENDIX D-4

SAMPLE HEAT AND MATERIAL BALANCE PROGRAM OUTPUT

Appendix D-4: Sample Heat & Material Balance Program

Date:	9/14/92	Test Start Time	4:00 PM
		Test Completion:	5:30 PM
Test Description:	Run 23C:MSW/Sludge/O2		
Sludge Source:			
O2 Enrichment Locations:			

INPUT:

Test Duration 1.5 hrs

Flue Gas

Mass Flow	4803	pph
O2	8.1	vol % dry
CO2	13.6	vol % dry
H2O	26.6	vol %
T (TFG4)	1190	F

OUTPUT:

Flow = 173 Lbmol/hr

Component	vol % wet	vol % dry	Lbmol/hr	Lb/hr
O2	5.9	8.1	10	329
CO2	10.0	13.6	17	759
N2	57.5	78.3	99.3	2,780
Moisture	26.6		46	827
Total	100.0	100.0	172.8	4,695

INPUT:

Combustion Air

Underfire	1783	Lb/hr
OFA+Nozzle	1175	Lb/hr
Tramp Air	700	Lb/hr
T UFA	106	F
T OFA	107	F
T Tramp Air	70	F

Underfire Air Distribution:

Drying	0.0	%
Combustion	87.4	%
Burnout	12.6	%

Oxygen

Combustion Zone	0	scfh
Burnout Zone	0	scfh
Overfire Air	2065	scfh
T	60	F

Air Products and Chemicals, Inc.

OUTPUT:

Air Flows	scfh	Lb/hr	Lbmol/hr
Tramp Air	9,148	700	24
Underfire	23,302	1,783	61
Overfire	15,356	1,175	41
Total	47,806	3,658	126

		Underfire	OFA + Nozzle	Tramp Air	Total
O2	Lbmol/hr	12.8	8.5	5.0	26.3
N2	Lbmol/hr	48.3	31.8	19.0	99.1
Moisture	Lbmol/hr	0.4	0.2	0.1	0.8

Underfire Air Flows:	scfh	Lb/hr	Lbmol/hr
Drying	0	0	0
Combustion	20,366	1,558	54
Burnout	2,936	225	8

Oxygen Flows:	scfh	Lb/hr	Lbmol/hr
Combustion	0	0.0	0.0
Burnout	0	0.0	0.0
Overfire	2,065	174.4	5.4
Total	2,065	174.4	5.4

		Combustion	Burnout	Overfire	Total
Comb Air	Lbmol/hr	54	8	41	102
Pure O2	Lbmol/hr	0.0	0.0	5.4	5.4
O2 Enrichment (mol %)		20.9	20.9	30.2	

INPUT:

Sludge / MSW / Ash

MSW Feed	**962**	Lbs
Sludge Feed	**555**	Lbs
Ash:		
Bottom Ash	**173**	Lbs
Fly Ash	**4**	Lbs

Sludge Composition (wt %)

C	**6.04**
H	**0.89**
O	**3.10**
Moisture	**84.97**
Ash	**5.00**
Total	100.00

Sludge HHV	**1217**	Btu/lb

Unburned Carbon

Bottom Ash	**0.1**	wt %
Fly Ash	**1.14**	wt %

Temperatures

MSW	**50**	F
Sludge	**50**	F
Bottom Ash	**700**	F
Fly Ash	**1190**	F

Air Products and Chemicals, Inc.

OUTPUT:

MSW Feed Rate:	641	Lb/hr
Sludge Feed Rate:	370	Lb/hr
Bottom Ash:	115	Lb/hr
Fly Ash:	3	Lb/hr

Sludge Flow:	Lb/hr	Lbmol/hr
C	22.3	1.9
H	3.3	3.3
O	11.5	0.7
Moisture	314.4	17.5
Ash	18.5	
Total	370.0	

Unburned Carbon	Lb	Lb/hr
Bottom Ash	0.2	0.1
Fly Ash	0.0	0.0

INPUT:

Heat & Material Balance Calculations

Furnace Temperature Profile:

	Rotameter, %	CW, lb/hr	T(F), out
R1	14	1,465	170
R2	10	1,046	113
R3	22	2,301	168
R4	26	2,720	133
R5	11	1,151	155
R6	14.5	1,517	143
C7	14	1,465	103
C8	12	1,255	83
C9	13.5	1,412	96
C10	14.5	1,517	120
C11	20	2,092	168
C12	14	1,465	166
C13	22.5	2,354	178
C14	16	1,674	161

CW Inlet 77 F

(Note: 100% = 20.9 gal/min)

OUTPUT:

Measured Heat Release:

Sensible Heat in Process Cooling Water:

Section #	MMBtu/hr
R1	136,205
R2	37,660
R3	209,433
R4	152,315
R5	89,757
R6	100,113
C7	38,079
C8	7,532
C9	26,833
C10	65,225
C11	190,393
C12	130,346
C13	237,730
C14	140,598

Total 1,562,220 Btu/hr

INPUT:

Air Products and Chemicals, Inc.

OUTPUT:

Sensible Heat in Cooling Water:	1,562,220	Btu/hr
Sensible Heat in Flue Gas:	1,485,504	Btu/hr
Latent Heat in Flue Gas:	876,111	Btu/hr
Sensible Heat in Bottom Ash:	18,453	Btu/hr
Sensible Heat in FlyAsh:	753	Btu/hr
Unburned Heat in Bottom Ash:	1,626	Btu/hr
Unburned Heat in Fly Ash:	429	Btu/hr
Latent Heat in Combustion Air:	14,428	Btu/hr
Estimated Heat Leak:	150,000	Btu/hr
Total Measured Heat Release:	4,109,524	Btu/hr

Energy Inputs:

Sensible Heat in Underfire Air	20,505	Btu/hr
Sensible Heat in Overfire Air	13,806	Btu/hr
Sensible Heat in Tramp Air	1,750	Btu/hr
Sensible Heat in Oxygen:	0	Btu/hr
Sensible Heat in MSW:	-6,410	Btu/hr
Sensible Heat in Sewage Sludge:	-3,700	Btu/hr
Subtotal (w/o Chemical Energy)	25,951	Btu/hr

Chemical Energy in MSW and Sludge:

Calculated Combined Waste Composition (MSW+Sludge):

	Lbmol/hr	Lb/hr	wt %
C	17.3	207.1	20.7
H	29.5	29.5	2.9
O	6.2	99.8	10.0
Moisture	30.5	548.3	54.7
Ash		118.0	11.8
Total		1002.7	100.0

INPUT:

OUTPUT:

Calculated MSW Composition:

	Lbmol/hr	Lb/hr	wt %
C	15.4	184.8	29.2
H	26.2	26.2	4.1
O	5.5	88.4	14.0
Moisture	13.0	233.9	37.0
Ash		99.5	15.7
Total		632.7	100.0

HHV Calcs (DBA Correlation) for Chemical Energy:

Combined Waste	4,173	Btu/lb	4.18	MMBtu/hr
MSW	5,896	Btu/lb	3.73	MMBtu/hr

Total Energy Input:

Subtotal (w/o Chemical Energy)	25,951	Btu/hr
Chemical Energy (Combined Waste)	4,180,622	Btu/hr
Total Energy Input:	4,206,572	Btu/hr

Heat Balance Closure / Convergence Check:

Overall Mass Balance:	0.82	%
Overall Energy Balance:	-2.36	%

Air Products and Chemicals, Inc.

INPUT:

OUTPUT:

List of Assumptions:

Standard	379	scf/lbmol
Tref	60	F
Flue Gas:		
MW	27.8	lb/lbmol
Cp	0.28	Btu/lb F
Combustion Air:		
Moisture	0.6	mol %
MW	29	lb/lbmol
Cp	0.25	Btu/lb F
Cooling Water:		
Cp	1	Btu/lb F
MSW/Sludge:		
MSW H/C	0.135	lb/lb
S H/C	0.155	lb/lb
Combined	0.142	lb/lb
Ash:		
Cp	0.25	Btu/lb F
Oxygen:		
purity	99.8	%
MW	32	lb/lbmol
Cp	0.22	Btu/lb F

Heat & Material Balance Program - List of Equations

Given: Flue Gas Flow (%CO2, %O2,%H2O)
Underfire Air Flow (%O2, %H2O)
Overfire Air Flow (%O2, %H2O)
Sludge Feed Rate (% C, H, O H2O, Ash)
Ash
Unburned Carbon

Heat Release:
Sensible Heat in Process Cooling Water = $(m,lb/hr)(Cp)(T_{out}-T_{in})$
Sensible Heat in Flue Gas = $(m,lb/hr)(Cp)(T_{out}-T_{ref})$
Latent Heat in Flue Gas = (flow,lbmol/hr)(18lb/lbmol)(1059.1 Btu/lb)
Latent Heat in Combustion Air = (flow,lbmol/hr)(18lb/lbmol)(1059.1 Btu/lb)
Sensible Heat in Ash = $(m,lb/hr)(Cp)(T_{out}-T_{ref})$
Unburned Heat in Ash = (m,lb/hr)(14,100 Btu/lb)
Latent Heat in Ash = (flow,lbmol/hr)(18lb/lbmol)(1059.1 Btu/lb)
Heat Leak = Estimated

Energy Input:
Sensible Heat in Combustion Air = $(m,lb/hr)(Cp)(T_{in}-T_{ref})$
Sensible Heat in Oxygen = $(m,lb/hr)(Cp)(T_{in}-T_{ref})$
Sensible Heat in MSW = $(m,lb/hr)(Cp)(T_{in}-T_{ref})$
Sensible Heat in Sewage Sludge = $(m,lb/hr)(Cp)(T_{in}-T_{ref})$

Combined Waste Composition:

$C_{waste} = CO2_{FG} + C_{ash}$

$H_{waste} = C_{waste} * (H/C)$

$O_{waste} = 2*O2_{FG} + 2*CO2_{FG} + (Hwaste/2) - 2*O2_{air} - 2*O2_{O2}$

$H2O_{waste} = H2O_{FG} - (H_{waste}/2) - H2O_{air}$

Ash_{waste} = Measured

MSW Composition:

$C_{MSW} = C_{waste} - C_{sludge}$

$H_{MSW} = H_{waste} - H_{sludge}$

$O_{MSW} = O_{waste} - O_{sludge}$

$H2O_{MSW} = H2O_{waste} - H2O_{sludge}$

$Ash_{MSW} = Ash_{waste} - Ash_{sludge}$

APPENDIX D-5

HEAT AND MATERIAL BALANCE PROGRAM RESULTS FOR ALL TESTS (UNCORRECTED DATA)

APPENDIX D-5: HEAT AND MATERIAL BALANCE PROGRAM RESULTS (1)

Phase I Baseline:

Run No.		3A	3B	4A	4B	7A	8A	13A	14A	Averages *
Run Date		1/22/92	1/22/92	1/23/92	1/23/92	1/29/92	1/30/92	2/14/92	2/19/92	(7A, 8A, 13A
Run Type		MSW	MSW	MSW	MSW	MSW	MSW	MSW	MSW	& 14A)
% Oxygen (OFA)										
% Oxygen (Burnout UFA)										
% Oxygen (Comb Zone UFA)										
Start Time		9:54	14:17	8:27	15:06	9:09	8:29	8:30	9:16	
End Time		13:04	17:12	11:21	16:56	11:13	11:01	10:30	11:44	
Duration	(min)	190	175	174	110	124	151	120	148	
MSW	(lb/hr)	702	690	758	754	602	668	539	579	
Sludge	(lb/hr)									
Oxygen	(lb/hr)									
Nozzle Atomizing Air	(lb/hr)									
Flue Gas Flow (measured)	(lb/hr)	4726	4584	4602	4501	4375	4388	4021	4614	4,350
Tramp Air (calculated)	(lb/hr)	725	580	600	1015	575	380	675	700	583
MSW Composition (calc'd)										
C	(wt %)	25.0	21.5	18.4	19.5	27.0	27.2	30.0	26.9	27.8
H	(wt %)	3.4	2.9	2.5	2.6	3.6	3.8	4.1	3.6	3.8
O	(wt %)	13.7	10.1	4.2	6.0	14.6	16.6	17.5	12.8	15.4
H2O	(wt %)	38.1	44.8	53.2	51.0	35.2	33.5	28.4	38.9	34.0
Ash	(wt %)	19.7	20.6	21.7	20.9	19.5	18.9	20.1	17.8	19.1
MSW HHV	(Btu/lb)	4838	4266	3960	4061	5232	5218	5730	5324	5376
MSW Moisture (measured)		11.9/14.4	11.9/14.4	16.3/17.1	16.3/17.1	24.4/30.8	31.6	29.3/22.5	39.3	
Mass Balance Closure	(%)	11.3	14.8	18.8	15.7	6.7	7.5	7.7	2.7	6.2
Heat Balance Closure (assumes 150,000 Btu/hr heat leak)	(%)	22.7	33.8	30.8	22.5	-0.4	-10.3	7.0	11.3	1.9

Notes -

1 Heat and material balances for each run were calculated with as measured data. Tramp air is estimated/calculated by closing the N2 balance given the N2 content of the measured flue gas flow.

* Runs 3A, 3B, 4A and 4B are not included in the baseline averages since heat and material balance closure is poor, due to the fact that the flue gas sampling probe was not functioning properly.

APPENDIX D-5: HEAT AND MATERIAL BALANCE PROGRAM RESULTS

Phase I O2 Enriched MSW Incineration:

Run No.		7B	13B	7C	13C	14B	9A	14C		Averages
Run Date		1/29/92	2/14/92	1/29/92	2/14/92	2/19/92	2/10/92	2/19/92		
Run Type		MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2		
% Oxygen (OFA)							25.1	25.4		
% Oxygen (Comb Zone UFA)		23.7	24.3	26.6	27.1	26.8		27.0		
Start Time		11:43	11:29	16:45	14:09	12:44	15:05	15:53		
End Time		14:30	13:29	19:43	15:59	15:13	18:06	18:09		
Duration	(min)	167	120	178	110	149	181	136		
MSW	(lb/hr)	677	564	702	633	720	586	711		
Sludge	(lb/hr)									
Oxygen	(lb/hr)	83	83	166	166	166	50	216		
Nozzle Atomizing Air	(lb/hr)									
Flue Gas Flow (measured)	(lb/hr)	4412	4271	4499	4127	4495	4210	4460		4,353
Tramp Air (calculated)	(lb/hr)	570	820	525	560	500	400	820		599
MSW Composition (calc'd)										
C	(wt %)	30.1	30.4	31.4	30.9	26.9	26.6	28.0		29.2
H	(wt %)	4.1	4.1	4.2	4.2	3.7	3.6	3.8		4.0
O	(wt %)	15.2	17	19.7	16.1	11.0	13.3	11.8		14.9
H2O	(wt %)	29.2	27.8	23.7	25.5	39.1	37.0	37.3		31.4
Ash	(wt%)	21.4	20.8	21.0	23.3	19.3	19.5	19.1		20.6
MSW HHV	(Btu/lb)	5934	5844	5898	6017	5501	5247	5631		5,725
MSW Moisture (measured)		24.4/30.8	29.3/22.5	24.4/30.8	29.3/22.5	39.3	28.5	39.3		
Mass Balance Closure	(%)	15.0	9.9	13.3	19.5	9.9	2.1	9.4		11.3
Heat Balance Closure	(%)	0.0	7.7	-6.3	5.4	-6.6	2.7	-3.6		-0.1
(assumes 150,000 Btu/hr heat leak)										

APPENDIX D-5: HEAT AND MATERIAL BALANCE PROGRAM RESULTS

Phase I O2 Enriched Coincineration (Sludge Pump/Sludge Atomization Nozzle Feed System):

Run No.		16A	16B	16C	17A	17B	17C		Averages
Run Date		2/26/92	2/26/92	2/26/92	2/27/92	2/27/92	2/27/92		(16A, 16B &
Run Type		MSW/S/O2	MSW/S/O2	MSW/S	MSW/S/O2	MSW/S/O2	MSW/S/O2		17B)
% Oxygen (OFA)							23.1		
% Oxygen (Comb Zone UFA)		24.9	26.5		24.9	25.0	24.4		
Start Time		10:15	13:45	17:30	11:10	13:59	16:39		
End Time		12:59	16:15	18:30	12:59	16:15	17:39		
Duration	(min)	164	150	60	109	136	60		
MSW	(lb/hr)	582	529	529	665	525	685		
Sludge	(lb/hr)	130	130	112	235	170	170		
Oxygen	(lb/hr)	100	133		100	100	111		
Nozzle Atomizing Air	(lb/hr)	240	240	240	240	240	240		
Flue Gas Flow (measured)	(lb/hr)	4504	4223	4172	4313	4137	4087		4,288
Tramp Air (calculated)	(lb/hr)	575	400	300	400	310	380		428
MSW Composition (calc'd)									
C	(wt %)	27.3	30.3	25.1	34.9	29.7	30.9		29.1
H	(wt %)	3.8	4.2	3.5	4.9	4.1	4.3		4.0
O	(wt %)	12.4	14.1	12.9	18.7	15.1	15.80		13.9
H2O	(wt %)	38.7	33.1	41.0	16.2	32.9	22.7		34.9
Ash	(wt %)	17.8	18.3	17.5	25.4	18.2	26.3		18.1
MSW HHV	(Btu/lb)	5483	6067	4328	6868	5890	6126		5,813
MSW Moisture (measured)		38.0	38.1	38.1	31.6	31.6	31.6		36
Mass Balance Closure	(%)	0.4	2.5	0.9	22.2	6.9	27.2		3.3
Heat Balance Closure	(%)	-2.8	-0.5	12.8	-10.9	-3.6	-9		-2.3
(assumes 150,000 Btu/hr heat leak)									

APPENDIX D-5: HEAT AND MATERIAL BALANCE PROGRAM RESULTS

Phase II Baseline:

Run No.		20	21	22A	23A	24A		Averages
Run Date		9/2/92	9/3/92	9/4/92	9/14/92	9/15/92		(w/o Run 21)
Run Type		MSW	Wet MSW	MSW	MSW	MSW		
Oxygen Enrichment Zone								
% Oxygen								
Start Time		17:06	13:00	10:34	9:30	9:29		
End Time		19:34	15:50	11:04	12:00	11:31		
Duration	(min)	148	170	30	150	122		
MSW	(lb/hr)	575	529	636	629	649		
Sludge	(lb/hr)							
Oxygen	(lb/hr)							
Nozzle Atomizing Air	(lb/hr)							
Flue Gas Flow (measured)	(lb/hr)	4712	4561	4740	4513	4692		4,664
Tramp Air (calculated)	(lb/hr)	870	1130	900	990	990		938
MSW Composition (calc'd)								
C	(wt %)	28.4	23.6	29.0	28.9	27.5		28.5
H	(wt %)	3.8	3.2	3.9	3.9	3.7		3.8
O	(wt %)	14.4	12.5	16.2	11.4	13.3		13.8
H2O	(wt %)	36.3	42.5	30.1	37.1	33.8		34.3
Ash	(wt %)	17.1	18.3	20.8	18.6	21.7		19.6
MSW HHV	(Btu/lb)	5,572	4,580	5,574	5,871	5,437		5,614
MSW Moisture (measured)		28	39/41	28	23.8/28.8	31.4/20.3		
Mass Balance Closure	(%)	-0.9	-13.7	0.5	14.0	6.2		4.9
Heat Balance Closure	(%)	8.1	2.2	-3.4	-1.5	-2.3		0.2
(assumes 150,000 Btu/hr heat leak)								

APPENDIX D-5: HEAT AND MATERIAL BALANCE PROGRAM RESULTS

Phase II MSW/Sludge Coincineration:

Run No.		22B	26B		Averages
Run Date		9/4/92	9/17/92		
Run Type		MSW/S	MSW/S		
Oxygen Enrichment Zone					
% Oxygen					
Start Time		11:10	11:05		
End Time		12:00	14:00		
Duration	(min)	50	175		
MSW	(lb/hr)	616	552		
Sludge	(lb/hr)	235	370		
Oxygen	(lb/hr)	0	0		
Nozzle Atomizing Air	(lb/hr)	305	392		
Flue Gas Flow (measured)	(lb/hr)	4827	4936		4,882
Tramp Air (calculated)	(lb/hr)	675	930		803
MSW Composition (calc'd)					
C	(wt %)	30.6	32.5		31.6
H	(wt %)	4.3	4.6		4.5
O	(wt %)	18.0	19.8		18.9
H_2O	(wt %)	26.0	22.3		24.2
Ash	(wt %)	21.0	20.9		21.0
MSW HHV	(Btu/lb)	5,934	6,295		6,115
MSW Moisture (measured)		28.0	29.4		
Mass Balance Closure	(%)	1.6	9.3		5.4
Heat Balance Closure	(%)	4.9	4.0		4.5
(assumes 150,000 Btu/hr heat leak)					

APPENDIX D-5: HEAT AND MATERIAL BALANCE PROGRAM RESULTS

Phase II O2 Enriched MSW/Sludge Coincineration:

Run No.		22C	23B	23C	24B	24C	25B	25C		Averages
Run Date		9/4/92	9/14/92	9/14/92	9/15/92	9/15/92	9/16/92	9/16/92		
Run Type		MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2		
Oxygen Enrichment Zone		OFA	OFA	OFA	OFA	OFA	Sludge Gun	Sludge Gun		
% Oxygen		36.3	39.1	34.1	43.7	41.2				
Start Time		14:16	12:24	16:00	11:35	14:34	9:50	14:00		
End Time		16:05	14:44	17:30	14:00	16:51	12:16	16:30		
Duration	(min)	109	140	90	145	137	146	150		
MSW	(lb/hr)	610	697	641	583	591	752	750		
Sludge	(lb/hr)	235	370	370	370	490	370	370		
Oxygen	(lb/hr)	210	244	171	302	272	272	328		
Nozzle Atomizing Air	(lb/hr)	305	392	392	392	392	0	0		
Flue Gas Flow (measured)	(lb/hr)	4774	4815	4803	4758	4702	4742	4605		4,743
Tramp Air (calculated)	(lb/hr)	1050	975	700	1035	800	960	990		930
MSW Composition (calc'd)										
C	(wt %)	34.7	43.8	29.2	46.4	47.0	28.5	31.6		37.3
H	(wt %)	4.9	6.2	4.1	6.6	6.8	4.0	4.5		5.3
O	(wt %)	15.9	25.4	14.0	25.0	21.1	10.7	17.2		18.5
H2O	(wt %)	21.8	2.7	37.0	-5.0	-6.2	29.5	16.6		13.8
Ash	(wt %)	22.8	21.9	15.7	27.1	31.4	27.3	30.2		25.2
MSW HHV	(Btu/lb)	7,026	8,529	5,896	9,197	9,633	5,934	6,231		7,492
MSW Moisture (measured)		28.0	23.8/28.8	23.8/28.8	31.4/20.3	31.4/20.3	20.6	20.6		
Mass Balance Closure	(%)	7.1	18.7	0.8	16.2	20.3	11.0	16.1		12.9
Heat Balance Closure	(%)	-9.9	-11.8	-2.4	-14.1	-6.6	-9.2	-10.1		-9.1
(assumes 150,000 Btu/hr heat leak)										

APPENDIX D-6

HEAT AND MATERIAL BALANCE PROGRAM RESULTS FOR ALL TESTS (CORRECTED DATA)

APPENDIX D-6: HEAT AND MATERIAL BALANCE PROGRAM RESULTS (CORRECTED DATA) (1)

Phase I Baseline:

Run No.		3A	3B	4A	4B	7A	8A	13A	14A	Averages
Run Date		1/22/92	1/22/92	1/23/92	1/23/92	1/29/92	1/30/92	2/14/92	2/19/92	(7A, 8A, 13A
Run Type		MSW	MSW	MSW	MSW	MSW	MSW	MSW	MSW	& 14A)
Oxygen Enrichment Zone										
MSW	(lb/hr)	702	690	758	754	602	668	539	579	
Sludge (wet)	(lb/hr)	0	0	0	0	0	0	0	0	
Sludge Solids	(wt %)									
Oxygen	(lb/hr)	0	0	0	0	0	0	0	0	
Nozzle Atomizing Air	(lb/hr)	0	0	0	0	0	0	0	0	
Dry Sludge/MSW	(wt %)									
Oxygen/Dry Sludge	(lb/lb)									
Flue Gas Flow (measured)	(lb/hr)	4726	4584	4602	4501	4375	4388	4021	4614	4,350
Flue Gas Flow (calculated)	(lb/hr)					4800	4800	4350	4740	4,673
Error in FG flow	(%)					9.7	9.4	8.2	2.7	7.4
Tramp Air (calculated)	(lb/hr)					975	750	940	810	869
Flue Gas Moisture (measured)	(%)	11.9	14.4	16.3	17.1	10.5	15.4	13.2	14.2	
Flue Gas Moisture (corrected)	(%)	14.4				14.1				
O2, dry	(%)	10.7	12.2	12.6	11.8	10.0	8.8	9.6	10.5	9.7
O2, wet	(%)	9.2	10.4	10.5	9.8	8.6	7.4	8.3	9.0	8.3
MSW Composition (calc'd)										
C	(wt %)					27.7	27.7	30.0	26.9	28.1
H	(wt %)					3.7	3.9	4.0	3.6	3.8
O	(wt %)					14.3	16.8	19.0	12.8	15.7
H2O	(wt %)					36.1	34.1	28.4	39.2	34.5
Ash	(wt %)					18.2	17.6	18.6	17.5	18.0
MSW HHV	(Btu/lb)					5400	5313	5623	5311	5,412
MSW Moisture (measured)						24.4/30.8	31.6	29.3/22.5	39.3	
Mass Balance Closure	(%)					0.1	0.5	0.03	0.4	0.3
Heat Balance Closure (assumes 150,000 Btu/hr heat leak)	(%)					-5.6	-14.8	4.9	10.4	-1.3

(1) Data was generated by adjusting the flue gas flow to close the mass balance for the measured MSW feed rate.
Tramp air is calculated by closing the N2 balance for the adjusted flue gas flow rate.

APPENDIX D-6: HEAT AND MATERIAL BALANCE PROGRAM RESULTS (CORRECTED DATA)

Phase I O2 Enriched MSW Incineration:

Run No.		7B	13B	7C	13C	14B	9A	14C		Averages
Run Date		1/29/92	2/14/92	1/29/92	2/14/92	2/19/92	2/10/92	2/19/92		
Run Type		MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2	MSW/O2		
% Oxygen (OFA)							25.1	25.4		
% Oxygen (Comb Zone UFA)		23.7	24.3	26.6	27.1	26.8		27.0		
MSW	(lb/hr)	677	564	702	633	720	586	711		
Sludge (wet)	(lb/hr)	0	0	0	0	0	0	0		
Sludge Solids	(wt %)									
Oxygen	(lb/hr)	83	83	166	166	166	50	216		
Nozzle Atomizing Air	(lb/hr)	0	0	0	0	0	0	0		
Dry Sludge/MSW	(wt %)									
Oxygen/Dry Sludge	(lb/lb)									
Flue Gas Flow (measured)	(lb/hr)	4412	4271	4499	4127	4495	4210	4460		4,353
Flue Gas Flow (calculated)	(lb/hr)	5200	4780	5160	5050	4900	4300	4850		4,891
Error in FG flow	(%)	17.9	11.9	14.7	22.4	9.0	2.1	8.7		12.4
Tramp Air (calculated)	(lb/hr)	1270	1290	1110	1370	830	475	1150		1,071
Flue Gas Moisture (measured)	(%)	14.1	12.7	13.7	12.9	16.9	11.1	16.6		
Flue Gas Moisture (corrected)	(%)						15.3			
O2, dry	(%)	10.0	11.2	10.7	12.1	10.9	10.2	11.6		11.0
O2, wet	(%)	8.6	9.8	9.2	10.5	9.1	8.6	9.7		9.4
MSW Composition (calc'd)										
C	(wt %)	30.4	30.7	31.3	30.4	26.6	26.6	27.6		29.1
H	(wt %)	4.2	4.1	4.2	4.1	3.7	3.6	3.7		3.9
O	(wt %)	17.5	18.3	22.6	21.5	13.5	13.6	14.3		17.3
H2O	(wt %)	29.6	28.1	23.6	25.2	38.7	37.0	36.9		31.3
Ash	(wt %)	18.4	18.8	18.2	18.8	17.6	19.1	17.4		18.3
MSW HHV	(Btu/lb)	5849	5841	5688	5565	5274	5226	5391		5,548
MSW Moisture (measured)		24.4/30.8	29.3/22.5	24.4/30.8	29.3/22.5	39.3	28.5	39.3		
Mass Balance Closure	(%)	0.9	0.4	0.3	0.1	0.7	0.1	0.4		0.4
Heat Balance Closure	(%)	-5.7	3.4	-9.8	1.3	-7.3	2.1	-4.4		-2.9
(assumes 150,000 Btu/hr heat leak)										

APPENDIX D-6: HEAT AND MATERIAL BALANCE PROGRAM RESULTS (CORRECTED DATA)

Phase I O2 Enriched MSW/Sludge Coincineration (Sludge Pump/Sludge Atomization Nozzle Feed System):

Run No.		16A	16B	16C	17A	17B	17C		Averages
Run Date		2/26/92	2/26/92	2/26/92	2/27/92	2/27/92	2/27/92		(16A, 16B & 17B)
Run Type		MSW/S/O2	MSW/S/O2	MSW/S	MSW/S/O2	MSW/S/O2	MSW/S/O2		
% Oxygen (OFA)							23.1		
% Oxygen (Comb Zone UFA)		24.9	26.5		24.9	25.0	24.4		
MSW	(lb/hr)	582	529	529	665	525	685		
Sludge (wet)	(lb/hr)	130	130	112	235	170	170		
Sludge Solids	(wt %)	18.0	15.4	15.4	14.0	14.0	16.9		
Oxygen	(lb/hr)	100	133		100	100	111		
Nozzle Atomizing Air	(lb/hr)	240	240	240	240	240	240		
Dry Sludge/MSW	(wt %)	4.02	3.78	3.26	4.95	4.53	4.19		
Oxygen/Dry Sludge	(lb/lb)	4.27	6.64	0.00	3.04	4.20	3.86		
Flue Gas Flow (measured)	(lb/hr)	4504	4223	4172	4313	4137	4087		4,288
Flue Gas Flow (calculated)	(lb/hr)	4504	4300	4172		4380			4,395
Error in FG flow	(%)	0.0	1.8	0.0		5.9			2.5
Tramp Air (calculated)	(lb/hr)	575	465	300		530			523
Flue Gas Moisture (measured)	(%)	19.1	18.3	15.2		18.9	17.1		
Flue Gas Moisture (corrected)	(%)			18.3	18.9				
O2, dry	(%)	10.3	10.6	9.9	9.3	10.7	10.9		10.5
O2, wet	(%)	8.3	8.7	8.1	7.5	8.7	9.0		8.6
MSW Composition (calc'd)									
C	(wt %)	27.3	30.1	25.1		29.1			28.8
H	(wt %)	3.8	4.2	3.5		4.0			4.0
O	(wt %)	12.4	14.5	12.9		15.3			14.1
H2O	(wt %)	38.7	33.3	41.0		33.7			35.2
Ash	(wt %)	17.8	17.8	17.5		18.0			17.9
MSW HHV	(Btu/lb)	5483	6005	4328		5730			5,739
MSW Moisture (measured)		38.0	38.1	38.1		31.6			
Mass Balance Closure	(%)	0.4	0.6	0.9		1.0			0.7
Heat Balance Closure (assumes 150,000 Btu/hr heat leak)	(%)	-2.8	-0.9	12.8		-5.6			-3.1

APPENDIX D-6: HEAT AND MATERIAL BALANCE PROGRAM RESULTS (CORRECTED DATA)

Phase II Baseline:

Run No.		20	21	22A	23A	24A		Averages
Run Date		9/2/92	9/3/92	9/4/92	9/14/92	9/15/92		
Run Type		MSW	Wet MSW	MSW	MSW	MSW		
Oxygen Enrichment Zone								
% Oxygen								
MSW	(lb/hr)	575	529	636	629	649		
Sludge (wet)	(lb/hr)	0	0	0	0	0		
Sludge Solids	(wt %)							
Oxygen	(lb/hr)	0	0	0	0	0		
Nozzle Atomizing Air	(lb/hr)	0	0	0	0	0		
Dry Sludge/MSW	(wt %)							
Oxygen/Dry Sludge	(lb/lb)							
Flue Gas Flow (measured)	(lb/hr)	4712	4561	4740	4513	4692		4,644
Flue Gas Flow (calculated)	(lb/hr)	4712		4740	5025	4750		4,807
Error in FG flow	(%)	0.0		0.0	11.3	1.2		3.1
Tramp Air (calculated)	(lb/hr)	870		900	1405	990		1,041
Flue Gas Moisture (measured)*		14.0*	15.0	14.0*	13.9	14.0*		
Flue Gas Moisture (corrected)					15.0	15.0		
O2, dry	(%)	10.0	11.2	9.0	9.8	9.7		9.9
O2, wet	(%)	8.6	9.5	7.7	8.3	8.2		8.5
MSW Composition (calc'd)								
C	(wt %)	28.4		29.0	27.4	26.0		27.7
H	(wt %)	3.8		3.9	3.7	3.5		3.7
O	(wt %)	14.4		16.2	10.8	12.6		13.5
H2O	(wt %)	36.3		30.1	41.9	37.4		36.4
Ash	(wt %)	17.1		20.8	16.1	20.5		18.6
MSW HHV	(Btu/lb)	5572		5574	5578	5125		5,462
MSW Moisture (measured)		28	39/41	28	23.8/28:8	31.4/20.3		
Mass Balance Closure	(%)	-0.9		0.5	0.5	0.5		0.1
Heat Balance Closure	(%)	8.1		-3.4	-4.0	-0.7		0.2
(assumes 150,000 Btu/hr heat leak)								

*Estimated, not measured

APPENDIX D-6: HEAT AND MATERIAL BALANCE PROGRAM RESULTS (CORRECTED DATA)

Phase II MSW/Sludge Coincineration:

Run No.		22B	26B		Averages
Run Date		9/4/92	9/17/92		
Run Type		MSW/Sldg	MSW/Sldg		
Oxygen Enrichment Zone					
% Oxygen					
MSW	(lb/hr)	616	552		
Sludge (wet)	(lb/hr)	235	370		
Sludge Solids	(wt %)	13.4	16.8		
Oxygen	(lb/hr)	0	0		
Nozzle Atomizing Air	(lb/hr)	305	392		
Dry Sludge/MSW	(wt %)	5.11	11.26		
Oxygen/Dry Sludge	(lb/lb)				
Flue Gas Flow (measured)	(lb/hr)	4827	4936		4,882
Flue Gas Flow (calculated)	(lb/hr)	4900	5300		5100
Error in FG flow	(%)	1.5	7.4		4.4
Tramp Air (calculated)	(lb/hr)	740	1190		965
Flue Gas Moisture (measured)		20.0*	20.6		
Flue Gas Moisture (corrected)			21.5		
O2, dry	(%)	7.3	8.6		8.0
O2, wet	(%)	5.8	6.8		6.3
MSW Composition (calc'd)					
C	(wt %)	30.6	29.6		30.1
H	(wt %)	4.3	4.2		4.25
O	(wt %)	17.9	17.9		17.9
H2O	(wt %)	26.5	30.6		28.55
Ash	(wt %)	20.7	17.7		19.2
MSW HHV	(Btu/lb)	5937	5742		5839.5
MSW Moisture (measured)		28	29.4		
Mass Balance Closure	(%)	0.4	0.3		0.4
Heat Balance Closure	(%)	4.2	2.9		3.5
(assumes 150,000 Btu/hr heat leak)					

*Estimated, not measured

APPENDIX D-6: HEAT AND MATERIAL BALANCE PROGRAM RESULTS (CORRECTED DATA)

Phase II O2 Enriched MSW/Sludge Coincineration:

Run No.		22C	23B	23C	24B	24C	25B	25C		Averages
Run Date		9/4/92	9/14/92	9/14/92	9/15/92	9/15/92	9/16/92	9/16/92		
Run Type		MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2	MSW/S/O2		
Oxygen Enrichment Zone		OFA	OFA	OFA	OFA	OFA	Sludge Gun	Sludge Gun		
% Oxygen (1)		36.3	39.1	34.1	43.7	41.2				
MSW	(lb/hr)	610	697	641	583	591	752	750		
Sludge (wet)	(lb/hr)	235	370	370	370	490	370	370		
Sludge Solids	(wt %)	15.1	15.4	15.0	15.0	13.3	14.6	13.4		
Oxygen	(lb/hr)	210	244	171	302	272	272	328		
Nozzle Atomizing Air	(lb/hr)	305	392	392	392	392	0	0		
Dry Sludge/MSW	(wt %)	5.82	8.18	8.66	9.52	11.03	7.18	6.61		
Oxygen/Dry Sludge	(lb/lb)	5.92	4.28	3.08	5.44	4.17	5.04	6.62		
Flue Gas Flow (measured)	(lb/hr)	4774	4815	4803	4758	4702	4742	4605		4,743
Flue Gas Flow (calculated)	(lb/hr)	4900	5050	4803	4758	5050	5100	4950		4,944
Error in FG flow	(%)	2.6	4.9	0.0	0.0	7.4	7.5	7.5		4.3
Tramp Air (calculated)	(lb/hr)	1100	900	700	750	825	1160	1080		931
Flue Gas Moisture (measured)		19.2	20.8	26.6	19.2	22.2	25.1	22.9		
Flue Gas Moisture (corrected)		20.5	26.0		25.0	27.0	26.5	26.5		
O2, dry	(%)	10.0	8.4	7.6	10.8	10.9	10.4	12.2		10.0
O2, wet	(%)	8.0	6.2	5.6	8.1	8.0	7.6	9.0		7.5
MSW Composition (calc'd)										
C	(wt %)	31.7	30.8	29.2	31.4	30.3	25.3	24.8		29.1
H	(wt %)	4.5	4.3	4.1	4.5	4.4	3.6	3.5		4.1
O	(wt %)	14.5	17.1	14.0	13.4	14.1	11.6	14.5		14.2
H2O	(wt %)	28.7	32.0	37.0	30.7	31.2	36.6	34.1		32.9
Ash	(wt %)	20.6	15.8	15.7	19.9	20.1	22.9	23.1		19.7
MSW HHV	(Btu/lb)	6438	6051	5896	6466	6173	5144	4826		5,842
MSW Moisture (measured)		28.0	23.8/28.8	23.8/28.8	31.4/20.3	31.4/20.3	20.6	20.6		
Mass Balance Closure	(%)	0.3	0.5	0.8	0.2	0.8	0.1	0.4		0.4
Heat Balance Closure (assumes 150,000 Btu/hr heat leak)	(%)	-8.5	-4.2	-2.4	-5.3	-1.3	-6.8	-4.1		-4.7

1 Sludge Gun atomization air not included in OFA flow.

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16. Abstract (Limit: 200 words)

This report provides a comprehensive summary of the pilot demonstration test program for oxygen-enriched coincineration of municipal solid waste and sewage sludge. It describes the pilot test facility, instrumentation, and methods of data collection and data analyses; describes how the test were executed; and discusses the test results. Recommendations for the future development in the current market place are also provided.

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