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EVALUATION OF OXYGEN-ENRICHED MSW/SEWAGE SLUDGE CO-INCINERATION DEMONSTRATION PROGRAM

by

CSI Resource Systems, Incorporated
Boston, Massachusetts 02110

and

The Solid Waste Association of North America
Silver Spring, Maryland 20910

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Project Officer

Lynnann Hitchens
Waste Minimization, Destruction, and Disposal Research Division
Risk Reduction Engineering Laboratory
Cincinnati, Ohio 45268

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This publication is part of a series of publications for the Municipal Solid Waste Innovative Technology Evaluation (MITE) Program. The purpose of the MITE program is to: 1) accelerate the commercialization and development of innovative technologies for solid waste management and recycling, and 2) provide objective information on developing technologies to solid waste managers, the public sector, and the waste management industry.

E. Timothy Oppelt
Risk Reduction Engineering Laboratory

ABSTRACT

This report provides an evaluation of a two-phased demonstration program conducted for the U.S. Environmental Protection Agency's Municipal Solid Waste Innovative Technology Evaluation Program, and the results thereof, of a recently developed method of sewage sludge management. This method, known as "oxygen-enriched co-incineration," is intended to allow the co-combustion of dewatered sewage sludge with municipal solid waste in a waste-to-energy facility without affecting solid waste throughput capacity or facility operational characteristics.

The report describes the demonstration program plan and the tests performed; assesses the execution of the demonstration program; provides the reported test results; and presents the results of an independent verification of the test results. Also evaluated in this report are the technical/operational, environmental regulatory/permitting, and economic implications of the commercial application of oxygen-enriched co-incineration. Finally, overall conclusions and recommendations are provided based on the evaluation.

This report was submitted in partial fulfillment of Cooperative Agreement 818238 under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers a period from October 4, 1991, to April 19, 1992.

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Appendices are not included in this document. Limited quantities are available from Lynnann Hitchens, U.S. EPA Center Hill Research Facility, 5995 Center Hill Road, Cincinnati, OH 45224.

FIGURES

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ACKNOWLEDGEMENTS

This report was prepared under the coordination of Lynnann Hitchens, U.S. Environmental Protection Agency (EPA) Municipal Solid Waste Innovative Technology (MITE) Program Project Manager at the Risk Reduction Engineering Laboratory, Cincinnati, Ohio, and Andy Miller of the Air & Energy Engineering Research Laboratory, Research Triangle Park, North Carolina. Contributors to and reviewers of this report include Charlotte Frola of the Solid Waste Association of North America (SWANA).

This report was prepared for EPA's MITE program by Richard D. Larson, Shawn Worster, Jan Sotan, and others of CSI Resource Systems, Incorporated.

The Department of Energy (DOE) funded the demonstration of this technology. EPA funded the evaluation at the pilot plant. This report contains mostly evaluation test information. Additional details on the technology can be found in the report, "Oxygen-Enriched Coincineration of MSW and Sewage Sludge," prepared by Air Products and Chemicals for the National Renewable Energy Laboratory (NREL) (a laboratory of the DOE), Golden, Colorado under Contract No. ZF-1-11115-1.

SECTION 1

INTRODUCTION

PROGRAM EVALUATED

In the past, sludge management planning has typically provided for a single method of reuse or disposal, such as landfilling. More recently, given stricter regulation of the disposal of sewage sludge in landfills and the banning of ocean dumping, the wastewater treatment industry has begun to recognize the need for multiple disposal and/or beneficial reuse options.

In the interest of providing an efficient sludge management option, Air Products and Chemicals, Inc. (APCI), has developed a concept known as "oxygen-enriched co-incineration." This technology is designed for use as a retrofit technology for existing waste-to-energy facilities. It utilizes a unique sludge injection system to feed sludge, that along with oxygen enrichment, provides for co-incineration, without sacrificing MSW capacity. Under Contract #ZF-1-11115-1, awarded by the Department of Energy, APCI developed a two-phased "pilot scale" demonstration program to demonstrate and optimize, to the extent possible, this co-incineration process. The program was concurrently selected by the MITE program for evaluation.

In the demonstration of their technology APCI had several objectives. The foremost of which was to demonstrate the mechanical feasibility of their technology by evaluating a variety of sludge feed and sludge distribution methods to optimize sludge combustibility. APCI also sought to determine the optimum ratio of oxygen to sludge for MSW and sludge co-incineration and to determine the effect of oxygen-enriched co-incineration on flue gas emissions and residual bottom and fly ashes.

The goal of the MITE evaluation was to verify the results of the pilot-scale testing, including the comparison of measured results with theoretical combustion calculations, formulate cost information for various retrofit scenarios, and consider the technical and operational implications of commercial application and scale-up.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions and recommendations are made pursuant to the evaluation:

- Technical issues requiring further evaluation prior to commercial application of APCI's oxygen-enriched co-incineration technology include:

    - confirmation of the long-term reliability of the proprietary sludge-feed system;

    - determination of the long-term impacts of introducing of sludge, oxygen, and moisture into existing waste-to-energy units relative to fouling, corrosion, performance, availability, and air pollution control equipment, including the potential need to add additional control technology or modify existing controls;

    - determination of the effect that introduction of high-moisture sludge and oxygen into the combustion environment will have on organic pollution emissions; and

    - confirmation of expected oxygen consumption per dry ton of sludge to a range consistent with the need to properly size and economically evaluate the oxygen production requirements.

- Based on conservative budgetary capital and operating costs, oxygen-enriched co-incineration of municipal sewage sludge in existing waste-to-energy facilities appears competitive, on a per-dry-ton basis, with alternative sludge treatment and disposal approaches, and therefore warrants further examination.

- The limited pilot test program indicates that sludge was co-incinerated with MSW up to a maximum ratio of 11.3 percent dry sludge per pound of MSW with the injection of 3.5 to 5.5 kilograms (pounds) of oxygen per kilogram (pound) of sludge while maintaining relatively constant MSW feed rates.

SECTION 2

DEMONSTRATION PROGRAM DESCRIPTION

PROGRAM OBJECTIVES

The specific objectives of APCI's demonstration program were to, primarily:

- determine the maximum ratio of dewatered sludge to MSW that can be co-incinerated with oxygen-enriched air;

and, in addition, to:

- evaluate a variety of sludge-feed and sludge-distribution methods to determine those that would optimize sludge combustibility;
- determine the effect of oxygen-enriched co-incineration on flue gas emissions and residual bottom and fly ashes;
- determine the most advantageous ratio of oxygen to sludge for MSW and sludge co-incineration; and
- evaluate the effect of oxygen-enriched combustion air on the MSW combustion rate during both MSW combustion alone and MSW/sludge co-incineration.

The demonstration program was conducted in two phases: Phase I took place in January and February of 1992, and Phase II took place in September 1992.

PILOT FACILITY DESCRIPTION

The pilot facility utilized in the demonstration program (see Figure 1) is owned and operated by Riley Stoker Corporation and is located at its Worcester, Massachusetts, research and development facility.

The pilot unit is a prototype of a full-scale Takuma system for mass-burning MSW. It is sized to burn a nominal 204 kilograms per hour (450 pounds per hour) of MSW, is 17 feet, 10 inches high and 11 feet, 9 inches long, and includes a reciprocating-grate stoker. The furnace is refractory lined and water-cooled by jacket sections to simulate a waste-heat boiler. Flue gas exiting the furnace is cooled prior to entering the baghouse and scrubber, and operating parameters are monitored by a computerized data acquisition system.

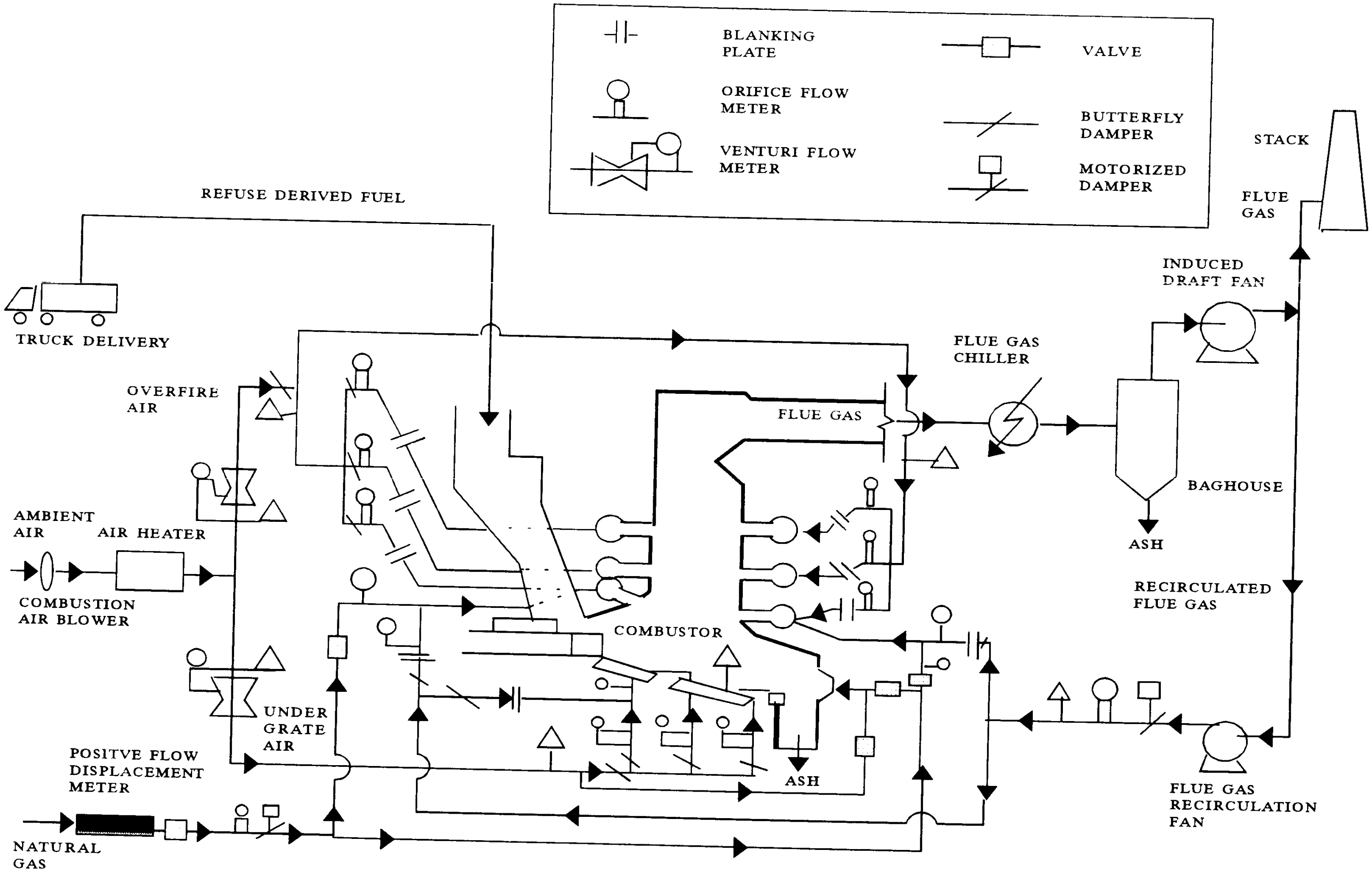


FIGURE 1. PROCESS FLOW DIAGRAM - RILEY PILOT MSW COMBUSTION FACILITY

Monitoring of NO_x, O_2, CO, CO_2, SO_2, and total hydrocarbons is provided by a continuous emissions monitoring system (CEMS) located prior to the air pollution control equipment. During Phase I, a separate HCl monitoring system was installed to monitor HCl. Combustion air and induced draft fans to remove flue gas are controlled by dampers. Provisions are provided for collecting both bottom and fly ash.

DEMONSTRATION PROGRAM PLAN

Planned Tests and Testing Schedule

Table 1 provides a list of the planned demonstration tests for both the Phase I and Phase II portions of the demonstration program. Table 2 provides descriptions of these tests.

Phase I of the program was intended to test the effects of oxygen-enriched combustion air on the combustion of, first, MSW alone, and then on MSW/sludge co-incineration. Phase II was intended to determine the optimal ratio of oxygen to sludge during co-incineration (including testing co-incineration with no oxygen enrichment), and the optimal ratio of MSW to sludge. During both phases, the parameters of MSW combustion alone were used as a baseline for all other measurements.

Quality Assurance/Quality Control Manual and Documentation

Using "Preparation Aids for the Development of Category III Quality Assurance Project Plans," EPA/600/8-91/005, published in February 1991, CSI developed a Quality Assurance/Quality Control (QA/QC) manual to ensure that the project needs would be met and that quality control procedures would be followed during testing sufficient to obtain data in a prescribed, consistent manner. In addition, modifications to the QA/QC manual were prepared by CSI in response to the modifications made to the Phase II test program by APCI, which focused primarily on the co-incineration of MSW and sewage sludge with oxygen enrichment.

Appendix A to this report includes copies of the QA/QC manual and Appendix E to the QA/QC manual.

PILOT FACILITY MODIFICATIONS

Prior to commencement of the demonstration tests, the following modifications were made to the pilot facility:

- An additional sludge-feed system was constructed to permit the introduction of sludge by using either an extrusion plate or an air-aspirated injection system. In both cases, sludge was delivered with a positive-displacement pump.
- An oxygen-enrichment control system was added to introduce oxygen during the combustion process to the overfire air and/or underfire

TABLE 1. PLANNED PILOT TEST SCHEDULE

	TEST DESCRIPTION		% SOLIDS SLUDGE	NO. OF RUNS
PHASE I:				
WEEK 1				
Day 1	Startup/Shakedown			2
Day 3	Baseline			2
WEEK 2				
Day 1	O_2-Enriched MSW Incineration	M1 & M2		2
Day 2	O_2-Enriched MSW Incineration	M3 & M4		2
Day 2	O_2-Enriched MSW Incineration	M5 & open		2
WEEK 3				
Day 1	O_2-Enriched Coincineration	C1	20%	3
Day 2	O_2-Enriched Coincineration	C2	20%	3
Day 3	O_2-Enriched Coincineration	open		3
WEEK 4				
Day 1	O_2-Enriched Coincineration	C3	20%	3
Day 2	O_2-Enriched Coincineration	C4	25%	3
Day 3	O_2-Enriched Coincineration	open		3
WEEK 5				
Day 1	O_2-Enriched Coincineration	C5	25%	3
Day 2	O_2-Enriched Coincineration	C6	25%	3
Day 3	O_2-Enriched Coincineration	open		3
PHASE II				
WEEK 1				
Day 1	Startup/Shakedown			
Day 2	Coincineration w/o O_2 Enrichment	CC1	20%	2
Day 3	Coincineration w/o O_2 Enrichment	CC2	20%	2

(continued)

TABLE 1. (continued)

	TEST DESCRIPTION		% SOLIDS SLUDGE	NO. OF RUNS
PHASE II (continued)				
WEEK 2				
Day 1	O_2-Enriched Coincineration	C7	20%	2
Day 2	O_2-Enriched Coincineration	C7 & C8	20%	2
Day 3	O_2-Enriched Coincineration	C8		2
WEEK 3				
Day 1	O_2-Enriched Coincineration	C9	20%	2
Day 2	Open		20%	2
Day 3	Open		20%	2

TABLE 2. DESCRIPTION OF TESTS

TEST DESCRIPTION AND TYPE	O_2 ENRICHMENT ZONE*	OXYGEN kg/hr (lb/hr)	OXYGEN ENRICHMENT TOTAL AIR (%)	SLUDGE (% SOLIDS)	DRY SLUDGE/ MSW (wt %)
Baseline:					
O_2-Enriched MSW Incineration:					
M1	Comb.		22.6		
M2	Comb.		23.3		
M3	OFA		23.3		
M4	Comb./BO		23.3		
M5	Comb.		24.1		
O_2-Enriched Coincineration:					
C1	Comb.	38.6 (85)		20%	5
C2	Comb.	54.4 (120)		20%	7.5
C3	Comb.	72.6 (160)		20%	10
C4	Comb.	43.1 (95)		25%	5
C5	Comb.	54.4 (120)		25%	7.5
C6	Comb.	43.1 (95)		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 O_2 Enrichment:					
CC1				20%	7.5
CC2				20%	10

* Comb = Combustion Zone of Underfire Air; OFA = Overfire Air; BO = Burnout Zone of Underfire Air; UFA = Underfire Air.

air (combustion and burnout zones) and to the air-aspirated injection system.

An HCl monitoring system was added to assess the impact of co-incineration on HCl emission rates. This was included only during Phase I testing.

SECTION 3

PROGRAM EXECUTION

FUEL UTILIZED

Processed MSW was procured and was used during the entire test program. The waste was characteristic of raw MSW; however, it had been shredded to a size of 15.2 centimeters (6 inches), with 50 to 60 percent of ferrous metals having been removed. It was necessary to utilize this processed MSW in order to comply with the 15.2-centimeter (6-inch) maximum particle size limitation of the pilot unit. The MSW was periodically sampled to develop ultimate and proximate analyses, which were compared with the results produced from the heat and material balance program. During each test run, samples were taken to determine the MSW moisture content.

Sewage sludge with a solids-content range of 22 to 25 percent was obtained from local wastewater treatment facilities. The material had been ground for Phase I testing, however, it was not ground for Phase II testing. APCI added water manually to the sludge to reduce its solids content to approximately 15 percent, which provided for better sludge pump performance. The sludge was periodically sampled and analyzed to determine its proximate/ultimate analysis and moisture content.

TESTS PERFORMED

Table 3 lists the test runs actually performed during Phase I and Phase II testing. The following tests, although proposed in the initial demonstration program plan, were not performed; their deletion constitutes the sole deviation from the demonstration program outlined in the QA/QC manual:

- Test M4 - Oxygen was to be added to the air supplying the burnout grate so as to reduce combustible loss. However, given that minimal combustible loss occurred while oxygen-enriched air was being supplied to the combustion zone, no benefit would have been obtained from this test.

- Tests C4, C5, and C6 - These tests required sludge with a 25-percent solids content to be fed to the pilot unit. However, in order to obtain adequate pump performance, the sludge solids content had to be maintained at less than 20 percent.

TABLE 3. TEST RUNS ACTUALLY PERFORMED

	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		7A, B, C
30–Jan	Baseline/Coincineration	Sludge Pump	8A, B
Week 3			
10–Feb	O2 Enriched MSW Incineration		9A
11–Feb	O2 Enriched Coincineration	Sludge Pump	10A, B
12–Feb	O2 Enriched Coincineration	Sludge Pump	11A
13–Feb	O2 Enriched Coincineration	Sludge Pump	12A, B
14–Feb	Baseline/O2 Enriched MSW Incineration		13A, B, C
Week 4			
19–Feb	Baseline/O2 Enriched MSW Incineration		14A, B, C
21–Feb	Shakedown		
Week 5			
26–Feb	O2 Enriched Coincineration	Atomization Nozzle	16A, B, C
27–Feb	O2 Enriched Coincineration	Atomization Nozzle	17A, 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	23A, B, C
15–Sep	Baseline/O2 Enriched Coincineration	Atomization Nozzle	24A, B, C
16–Sep	Baseline/O2 Enriched Coincineration	Atomization Nozzle	25B, C
17–Sep	Coincineration	Atomization Nozzle	26B

Flue gas emissions were continuously monitored for O_2, CO_2, CO, NO_x, SO_2, and total hydrocarbons during Phase I and Phase II testing. HCl emissions were monitored during Phase I testing only. The emissions were measured prior to the air pollution control system and provided information relative to the impact of co-incineration on flue gas emissions prior to the air pollution control system. Bottom and fly ash were analyzed to assess the impact co-incineration would have on the heavy metal content of the residual ash.

PROBLEMS ENCOUNTERED

As is to be expected in any pilot program, certain problems were encountered during the demonstration test which impeded the collection of data. These problems were:

- MSW pluggage of the feed chute. As previously stated, the MSW was a shredded fuel with approximately 50 to 60 percent of ferrous material removed. However, due to the presence of a significant amount of large-sized ferrous and non-ferrous metals, bridging occurred in the feed chute, which interrupted flow to the pilot plant and resulted in combustion temperature drops and a commensurate rise in CO production.

- Broken reciprocating-grate rods, which before being replaced required the unit to be shut down and cooled off.

- Corrosion of the flue gas sampling probe, which resulted in unsuccessful runs due to poor-quality data.

These problems, although nuisances, were not the results of problems with the technology being tested. However, the following problem was considered to have been related to the technology development.

The initial sludge-feed system, in place during Phase I of the demonstration program, included an extrusion plate that fed a consistent rate of sludge to the top of the refuse bed. The extrusion plate consisted of a series of holes .32 to 1.27 centimeters (1/8 to 1/2 inches) in diameter and was fixed in place. The slow grate speed, however, allowed the sludge to puddle; consequently, a minimum amount of sludge was combusted.

The orifice plate holes also continuously plugged, further confounding the effort. The system was modified to enable sludge to be spread manually by hose in the feed hopper and manually by shovel over the MSW as it was being fed into the in-feed conveyor. However, these approaches also proved unsuccessful.

During the latter part of Phase I testing, APCI acquired a proprietary air-aspirated nozzle, which was installed and functioned satisfactorily. The nozzle introduced the sludge to the pilot unit in small enough particle sizes to allow the sludge to burn successfully in suspension. (This was verified during test runs 16A, 16B, and 17B, where bottom ash carbon content was less than one percent.)

DATA ACQUISITION SYSTEM

Plant operating data for all runs was collected manually and with an automatic, computer-based data acquisition system. Table 4, developed by APCI, lists the data acquired, and Figure 2, also developed by APCI, indicates the location of instrumentation. Additionally, thermocouples were installed to measure grate temperature, and HCl monitoring equipment was provided during Phase I. Bottom and fly ash was sampled during each run and analyzed for:

- arsenic
- barium
- cadmium
- chromium
- lead
- mercury
- selenium
- silver
- chloride
- sulfate
- unburned carbon

"Toxicity characteristic leaching procedure" (TCLP) was not performed given that, during the pilot test, fly ash was collected separately, prior to the air pollution control system, and therefore would not have had the benefit of mixing with lime from a dry scrubber system as is common in commercial installations. It was therefore agreed that TCLP testing would not be performed in that it would not be representative of the ash generated by commercial facilities. Flue gas moisture was determined manually once per test run. All instrumentation was calibrated prior to and after each run to ensure data accuracy.

APCI analyzed all the raw data collected to screen out non-representative information collected during periods when the feed hopper was plugged or when failure of the flue gas sampling probe or incomplete combustion of sludge, determined by high ash carbon content, occurred. As a result of this data screening, the runs in Table 5 were eliminated. The successful runs that remained and were used in the evaluation are given below in Table 6.

TABLE 6. COMPLETED TEST RUNS

TEST DESCRIPTION	PHASE I TEST RUNS	PHASE II TEST RUNS
Baseline	7A, 8A, 13A, 14A	20, 22A, 23A, 24A
MSW/O_2	7B, 7C, 9A, 13B, 13C, 14B, 14C	
MSW/Sludge		22B, 26B
MSW/O_2/Sludge	16A, 16B, 17B	22C, 23B, 23C, 24B, 24C, 25B, 25C

TABLE 4. DATA ACQUIRED

LOCATION	FLOW OR WEIGHT	TEMP	O2	CO2, SOC, NOx, CO, THC	MOISTURE	RCRA METALS	Cl/S	CARBON CONTENT	FREQUENCY (APPROXIMATE)
Sampling Locations:									
SP1 (MSW)	X								N/A
SP2 (Bottom Ash)	X					X	X	X	(See Sect. 5.2)
SP3 (Economizer Ash)	X					X	X	X	(See Sect. 5.2)
SP4 (Combustion Control)	X		X						10 Min.
SP5 (Hot Flue Gas)	X				X				(See Sect. 5.2)
SP6 (CEMS)			X	X					10 Min.
SP7 (Baghouse Ash)	X					X	X	X	(See Sect. 5.2)
SP8 (Sewage Sludge)	X				X	X	X		N/A
Water Jacketed Sections:									
TI–T15 (WC, In)		X							10 Min.
T16–T30 (CW, Out)		X							10 Min.
F1–F15 (CW Flow)	X								1/Hour
Gas Coolers:									
T31 (CW, Out)		X							10 Min.
T32 (CW, Out)		X							10 Min.
F16 (CW Flow)	X								1/Hour
F17 (CS Flow)	X								1/Hour
Flue Gas:									
T101 (Temp Control Point)		X							10 Min.
T102 (C8)		X							10 Min.
T103 (C10)		X							10 Min.
T104 (C12)		X							10 Min.
T102 (Outlet GC #1)		X							10 Min.
T106 (Outlet GC #2)		X							10 Min.
T107 (To Scrubber)		X							10 Min.
Combustion Air:									
F101 (Total Underfire Air)	X								10 Min.
F102 (Overfire Air)	X								10 Min.
F103 (Drying Zone)	X								10 Min.
F104 (Combustion Zone)	X								10 Min.
F105 (Burnout Zone)	X								10 Min.

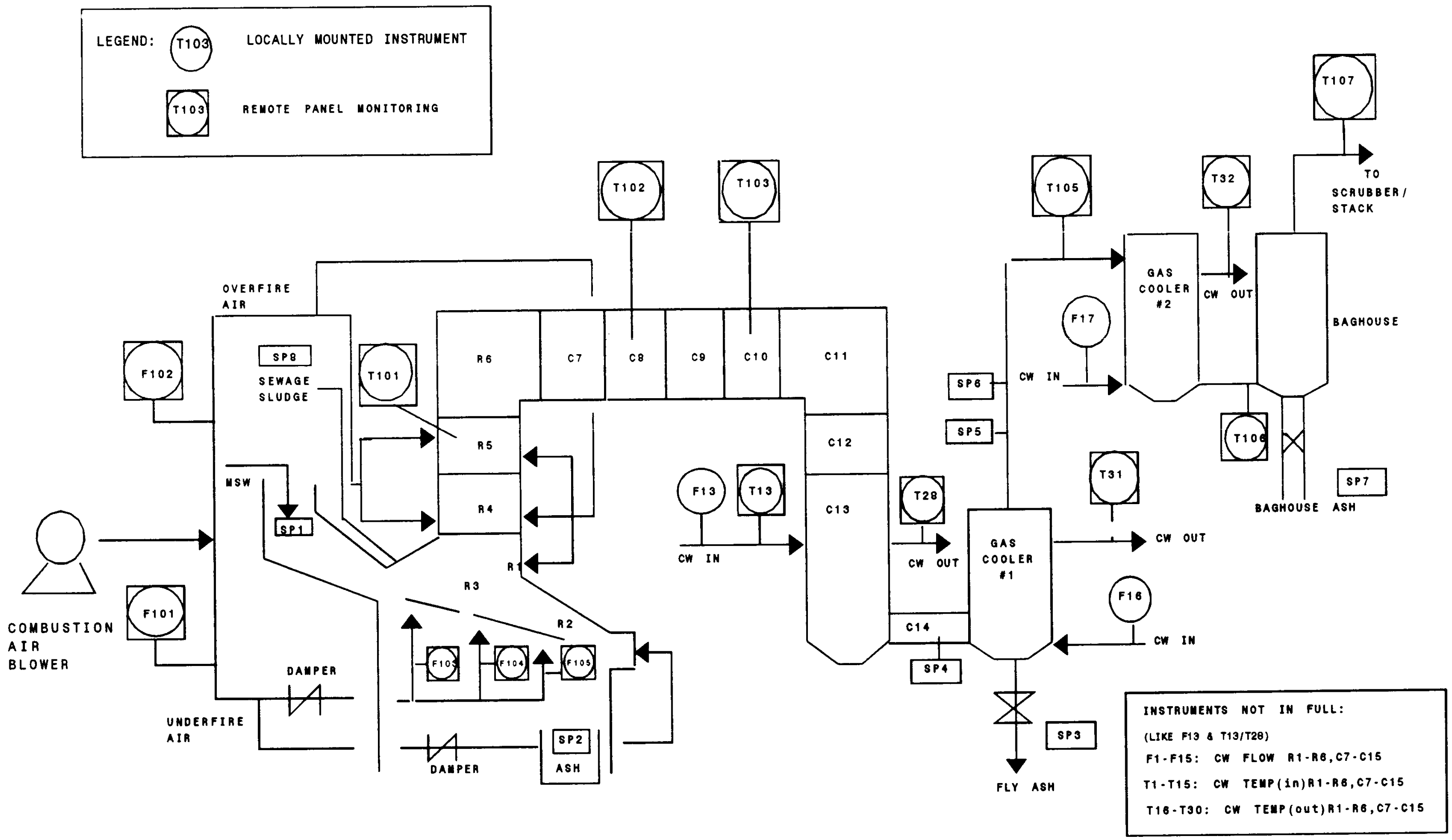


FIGURE 2. RILEY INSTRUMENTATION AND SAMPLING POINTS

TABLE 5. ELIMINATED TEST RUNS

RUNS	PROBLEM
3A	Flue gas sampling probe had been leaking
3B	Flue gas sampling probe had been leaking
4A	Flue gas sampling probe had been leaking
4B	Flue gas sampling probe had been leaking
8B	Incomplete combustion of sludge when utilizing extrusion plate
10A	Incomplete combustion of sludge when utilizing extrusion plate
10B	Incomplete combustion of sludge when utilizing extrusion plate
11A	Incomplete combustion of sludge when utilizing extrusion plate
12A	Incomplete combustion of sludge when utilizing extrusion plate
12B	Incomplete combustion of sludge when utilizing extrusion plate
17A	Poor energy balance closure and sludge atomization nozzle erosion problems.
17C	Poor energy balance closure and sludge atomization nozzle erosion problems.
21	Poor energy balance closure.

DATA PRODUCTION

Phase I

Baseline Testing--

The testing program required a baseline to be established, which required firing MSW only and establishing the base operating conditions. The control point for the baseline was 8.5 percent oxygen concentration in the flue gas (on a wet basis) while maintaining a slight negative pressure in the combustion chamber. Four baseline runs were performed (7A, 8A, 13A, and 14A).

Oxygen-Enriched MSW Incineration--

The effect of oxygen enrichment on MSW combustion with no sewage sludge was determined during runs 7B, 7C, 9A, 13B, 13C, 14B, and 14C.

The control point was 8.5 percent oxygen concentration in the flue gas, on a wet basis. The mass limit of the grate was also intended for use as a control point. However, due to induced draft fan limitations, the grate mass limit could not be reached. As a surrogate, the fire-line position, where visible combustion actually commences, on the grate was used. The reference point fire-line position was established during the baseline runs and was visually monitored through an observation port located at the ash discharge end of the pilot test unit. To provide margin, the fire-line reference point was established at a position where the induced draft fan was operating at less than full capacity.

Oxygen-Enriched Co-Incineration of MSW and Sewage Sludge--

During the latter part of Phase I testing, APCI acquired a proprietary air-aspirated nozzle, which was installed, functioned satisfactorily, and enabled runs 16A, 16B, and 17B to be performed.

Phase II

Due to the problems encountered during Phase I, which limited actual test results of MSW and sewage sludge co-incineration with oxygen to those obtained from three runs, the Phase II test plan was modified by APCI to focus more on the co-incineration of MSW and sewage sludge with oxygen than on determining optimal ratios.

Baseline Testing--

Phase II testing was conducted in September 1992, seven months after the completion of Phase I testing, and consequently required additional MSW to be obtained. To account for any differences from the MSW used during Phase I testing, baseline testing was again performed. Control points were 8.5 percent oxygen concentration in the flue gas, on a wet basis, while maintaining the fire line at a fixed point. Four baseline runs (20, 22A, 23A, and 24A) were performed.

MSW and Sewage Sludge Co-Incineration Without Oxygen Enrichment--

To determine the effects on the pilot unit of co-incinerating MSW and sewage sludge without oxygen enrichment, testing was performed at dry-sludge-to-

MSW ratios of 5.1 percent and 11.3 percent, using the sludge atomization nozzle. Control points were 8.5 percent oxygen concentration in the flue gas, on a wet basis, and maintaining the fire line at a fixed point determined during baseline testing. Two co-incineration with no oxygen-enrichment test runs (22B and 26B) were performed.

Oxygen-Enriched Co-Incineration of MSW and Sewage Sludge--

The control points for the oxygen-enriched co-incineration of MSW and sewage sludge were 8.5 percent oxygen concentration in the flue gas, on a wet basis, and maintaining the fire line at a fixed point determined during baseline testing. Oxygen was introduced through the sludge atomization nozzle and the underfire and/or overfire air at rates ranging from 77.6 to 137.0 kilograms per hour (171 to 302 pounds per hour). Seven oxygen-enriched co-incineration test runs (22C, 23B, 23C, 24B, 24C, 25B, and 25C) were performed.

SECTION 4

PROGRAM RESULTS

DATA REDUCTION

Throughout both phases of the entire test program, data was collected to enable APCI to perform heat and material balance calculations for each test performed.

Based on the data collected, and by accounting for all the mass, the mass and energy balance program solved for the MSW ultimate analysis (i.e., C, H, O, H_2O, and ash). From the ultimate analysis, the MSW higher heating value was estimated, which was used in determining the total energy input to the system. Figure 3, developed by APCI, provides a schematic representation of the heat and material balance.

To account for air leakage, the results were adjusted by varying the tramp air flow until the amount of total mass entering the system and the amount of total mass leaving the system closed to within 1 percent.

Using the boiler as a calorimeter to account for total heat and accounting for the mass flow around the combustion unit provides a better estimation of the average MSW composition and HHV combusted during a run than a laboratory analysis of a grab sample. This is due to the nonhomogenous nature of MSW, which does not lend itself to accurate determination of composition over short time spans with few samples. Sludge, on the other hand, has more uniform consistency, and laboratory analysis provides a reasonable representation of sludge ultimate/proximate analysis and heat content.

Phase I

Oxygen-Enriched MSW Incineration--
The effect of oxygen enrichment on MSW combustion with no sewage sludge was determined by runs 7B, 7C, 13B, 13C, 14B, and 14C and was compared against baseline runs 7A, 8A, 13A, and 14A.

APCI's reported results, based on actual data and not normalized to a constant flue gas flow rate and oxygen concentration (wet) in the flue gas, indicated that by adding 98.0 kg/hr (216 lbs/hr) of oxygen, MSW throughput increased to 322.5 kg/hr (711 lbs/hr), or almost 20 percent over the 270.8 kg/hr (597 lbs/hr) average baseline case.

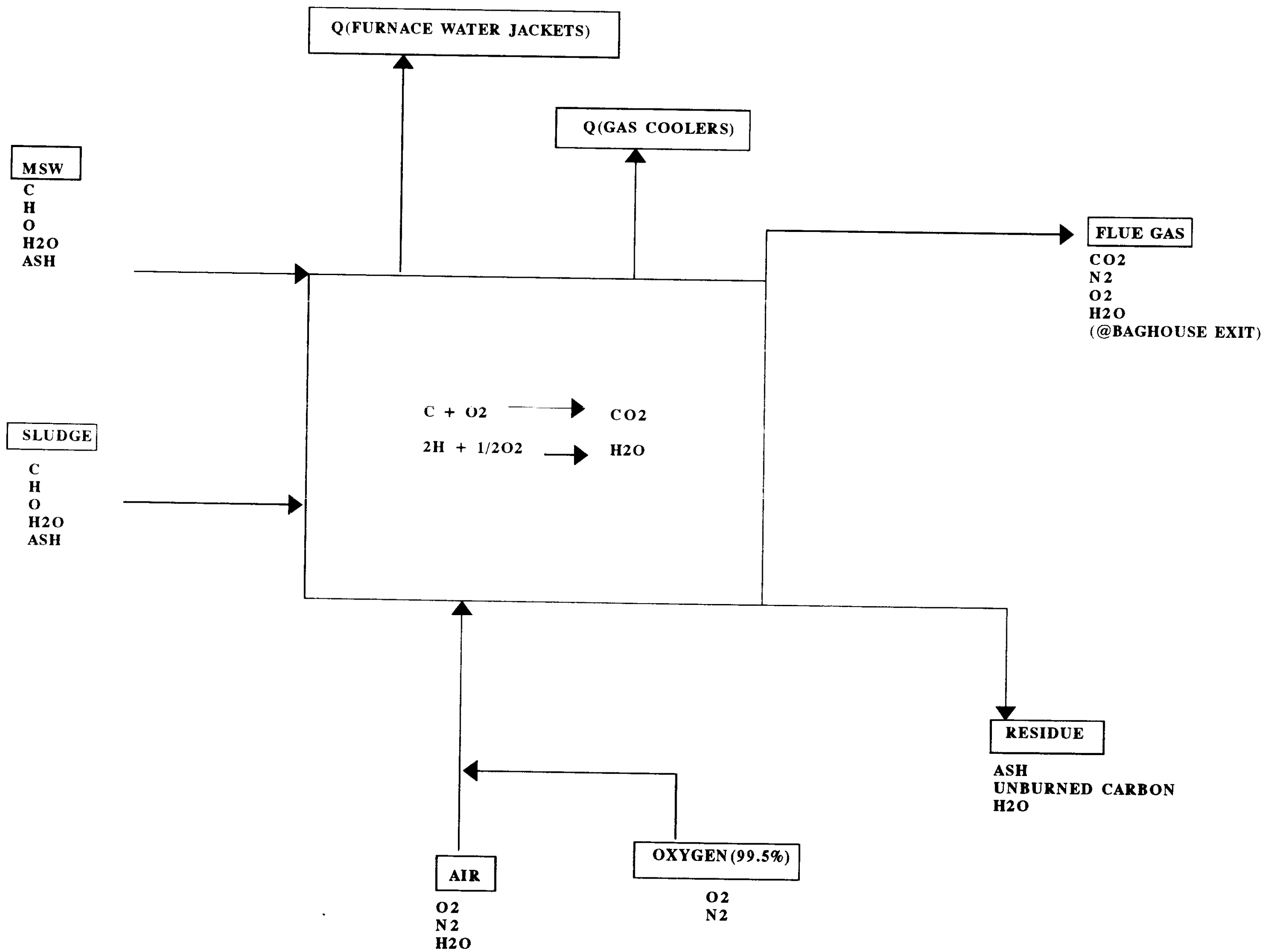


FIGURE 3. SCHEMATIC REPRESENTATION OF HEAT AND MATERIAL BALANCES

Normalizing both the baseline data and the results of the oxygen-enriched co-incineration runs to 8.5 percent oxygen concentration (wet) in the flue gas and a 2,268 kg/hr (5,000 lb/hr) flue gas flow rate, as shown in Table 7, enabled an approximate 24-percent increase in MSW throughput with the addition of 98 kg/hr (216 lbs/hr) of oxygen. Figures 4A and 4B provide plots of these results in metric and U.S. units, respectively.

Oxygen-Enriched Co-Incineration of MSW and Sewage Sludge--
The effects of oxygen enrichment on the co-incineration of MSW and sewage sludge were determined during runs 16A, 16B, and 17B.

During the latter part of Phase I testing, APCI acquired a proprietary air-aspirated nozzle which functioned satisfactorily. The nozzle introduced sludge to the pilot unit in small enough particle sizes to allow the sludge to burn in suspension.

The bottom ash carbon content for runs 16A, 16B, and 17B was analyzed, with results of .33, .91, and .68 on a weight-percent basis, respectively, indicating good burnout.

Runs 16A, 16B, 17B, and the baseline runs were normalized to 8.5 percent oxygen concentration, on a wet basis, in the flue gas and a flue gas flow rate of 2,268 kg/hr (5,000 lbs/hr).

The results of runs 16A, 16B, and 16C were compared against the average of the results of the baseline runs, and, as shown in Figures 5A (metric units) and 5B (U.S. units), while maintaining a consistent MSW-feed rate, flue gas flow, and oxygen concentration, sludge was co-incinerated with MSW with the addition of oxygen. During these runs the atomizing nozzle was corroding. Material modifications corrected this problem for Phase II testing.

Phase II

MSW and Sewage Sludge Co-Incineration without Oxygen Enrichment--
Three runs (16C, 22B, and 26B) were conducted with sludge co-incinerated with MSW with no oxygen enrichment. Table 8, developed by APCI, is a comparison of all data obtained from baseline runs, MSW and sludge co-incineration runs without oxygen enrichment, and MSW co-incineration runs with oxygen enrichment, normalized to an oxygen concentration of 8.5 percent (on a wet basis) in the flue gas. The average first-pass temperature (i.e., T101 on Figure 2) decreased from the baseline 835°C (1,535°F) to 729°C (1,345°F). As shown in Figures 6A (metric units) and 6B (U.S. units), at the point for zero oxygen addition (which is the average of the co-incineration runs without oxygen enrichment) there was a decline in the MSW-feed rate with the addition of sludge. The total MSW and sludge feed rate (fuel rate) increased, however, over the baseline.

Table 9, also developed by APCI, shows increases in the concentration of CO and total hydrocarbon in the flue gas for runs 22B and 26B.

TABLE 7. MSW THROUGHPUT AS A FUNCTION OF OXYGEN ADDITION*

	BASELINE (7A, 8A, 13A, 14A)	83 LB/HR O2 (7B, 13B)	166 LB/HR O2 (7C, 13C, 14B)	216 LB/HR O2 (14C)
APCI				
MSW Range [kg/hr (lb/hr)]	244–303 (539–668)	256–307 (564–677)	287–327 (633–720)	323 (711)
MSW Average [kg/hr (lb/hr)]	271 (597)	281 (620)	311 (685)	323 (711)
O2 Flow Average [kg/hr (lb/hr)]	0 (0)	38 (83)	75 (166)	95 (216)
FG Flow [kg/hr (lb/hr)] (Corrected)	2,120 (4,673)	2,263 (4,990)	2,285 (5,037)	2,200 (4,850)
O2 Wet % (Flue Gas)	8.3	9.1	9.6	9.7
% Increase in MSW Throughput	0	3.9	14.7	19.1
Corrected to 8.5% O2 & 2,268 kgs/hr (5,000) lbs/hr) FG Flow				
MSW Average [kg/hr (lb/hr)]	283 (623)	294 (649)	337 (744)	365 (805)
O2 Flow Avg. [kg/hr (lb/hr)]	0 (0)	39 (87)	82 (180)	111 (245)
FG Flow [kg/hr (lb/hr)]	2,268 (5,000)	2,268 (5,000)	2,268 (5,000)	2,268 (5,000)
O2 Wet %	8.5	8.5	8.5	8.5
% Increase in MSW Throughput	0	4.2	19.4	29.2

* Normalized from APCI test results.

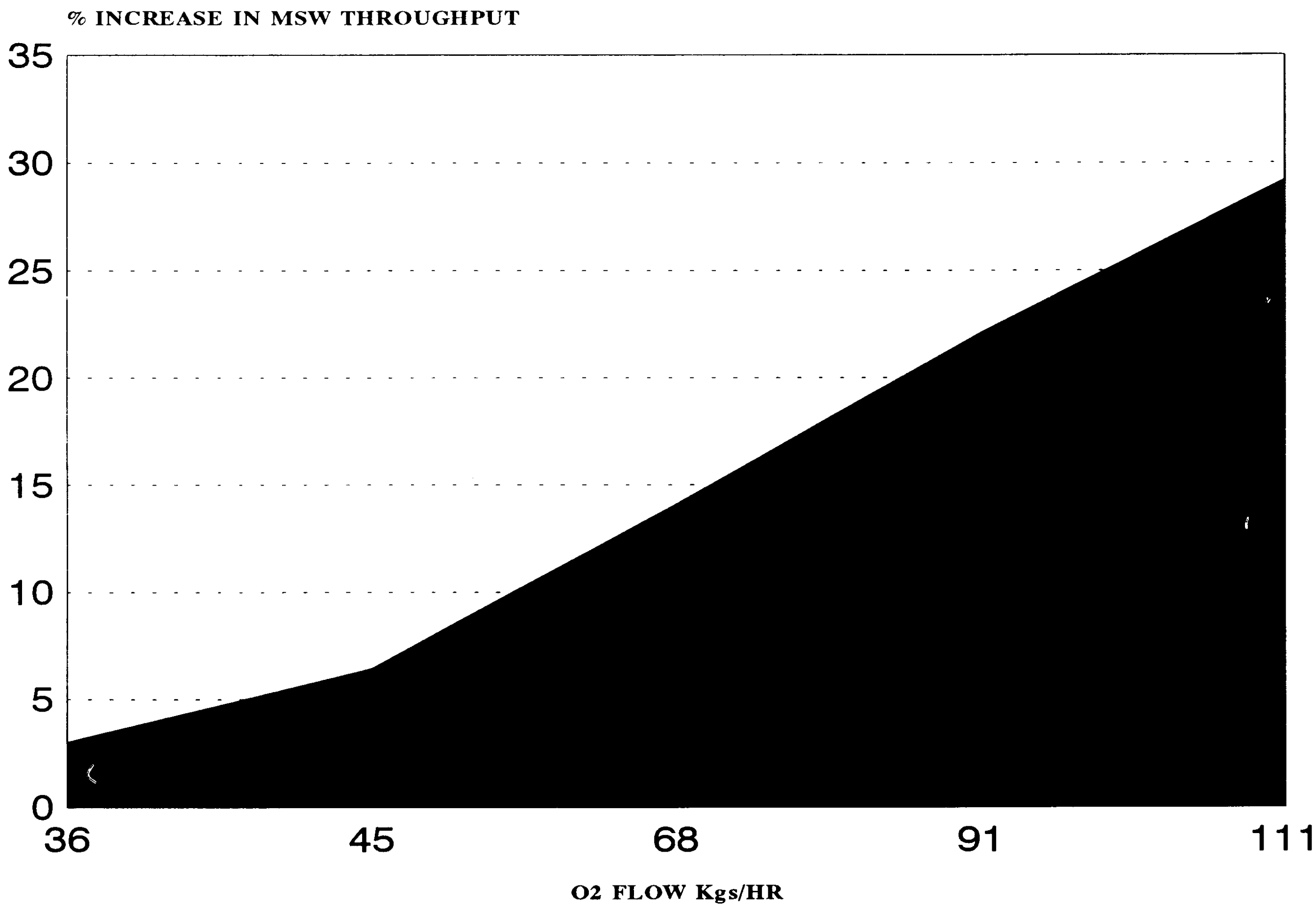


FIGURE 4A. MSW THROUGHPUT AS A FUNCTION OF OXYGEN FLOW (METRIC)
NORMALIZED TO 2268 Kg/Kg FLUE GAS FLOW AND 8.5% O_2 (WET) IN THE FLUE GAS

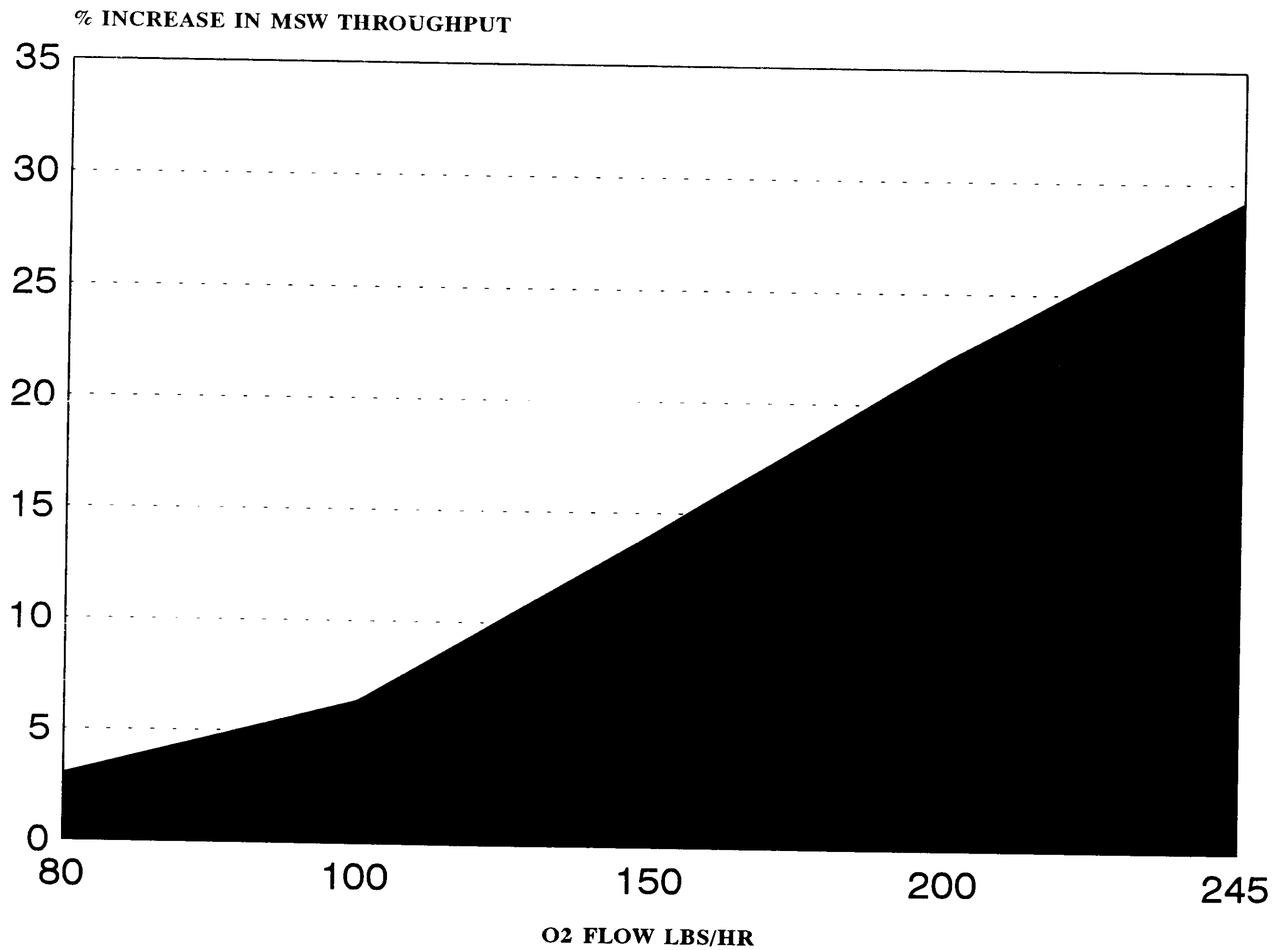
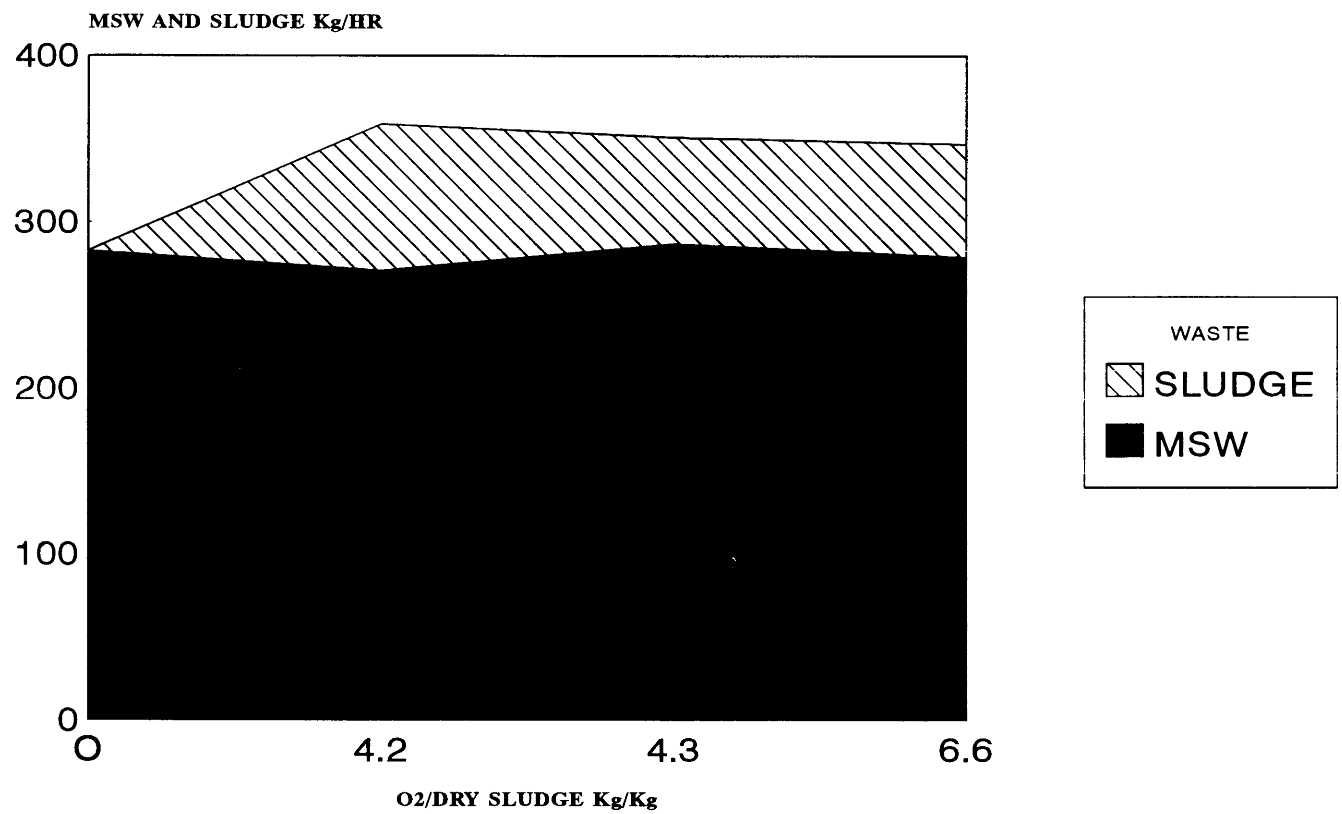


FIGURE 4B. MSW THROUGHPUT AS A FUNCTION OF OXYGEN FLOW (U.S. UNITS)

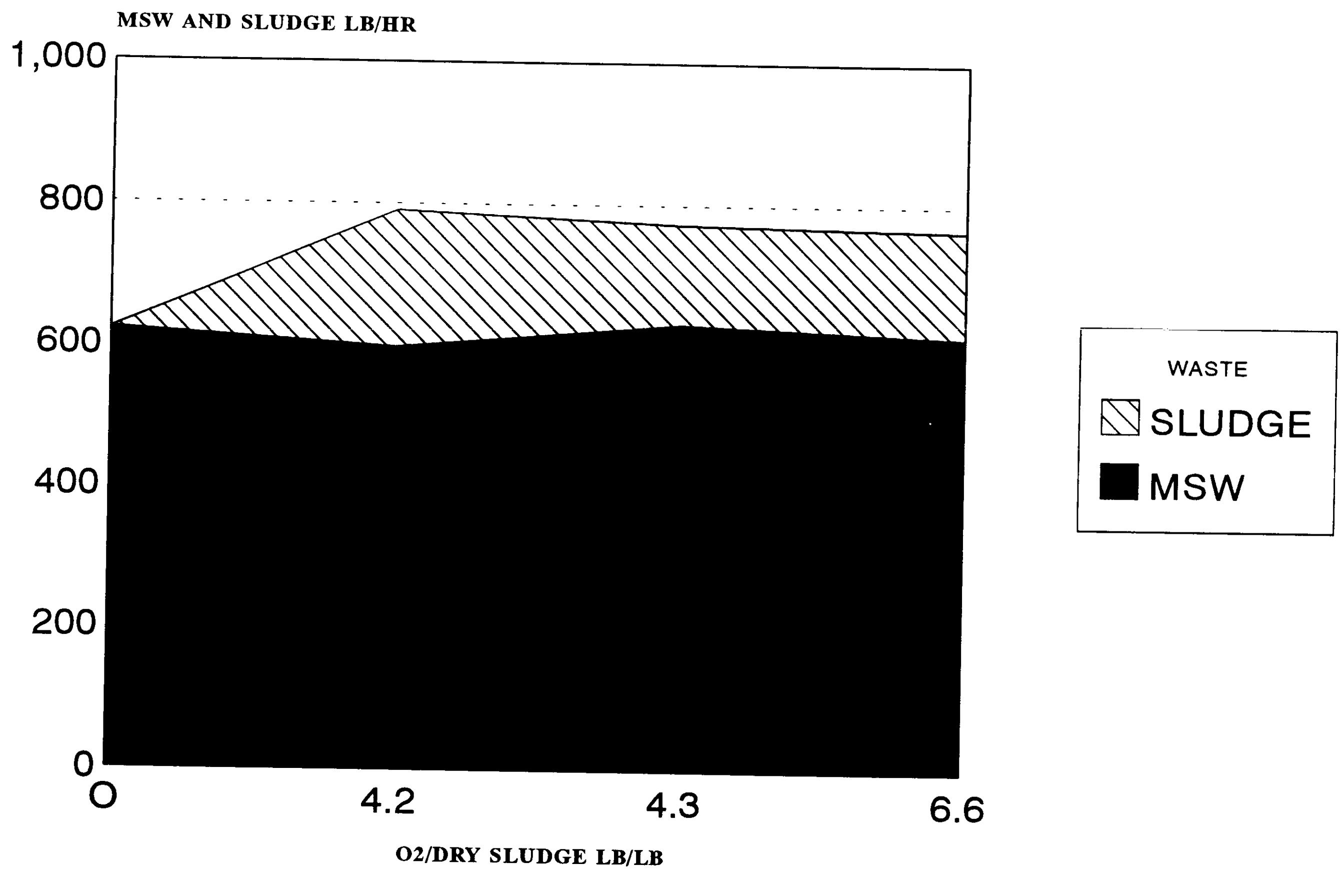
NORMALIZED TO 5000 LB/HR FLUE GAS FLOW AND 8.5% O_2 (WET) IN THE FLUE GAS



ALL FLOWS NORMALIZED TO 8.5% O2 IN THE FLUE GAS
ALL FLOWS NORMALIZED TO A FLUE GAS FLOW OF 2268 Kg/HR

FIGURE 5A. CUMULATIVE MSW AND SLUDGE PROCESSING CAPACITY (METRIC)

AS A FUNCTION OF OXYGEN ADDITION PHASE 1
NORMALIZED RESULTS



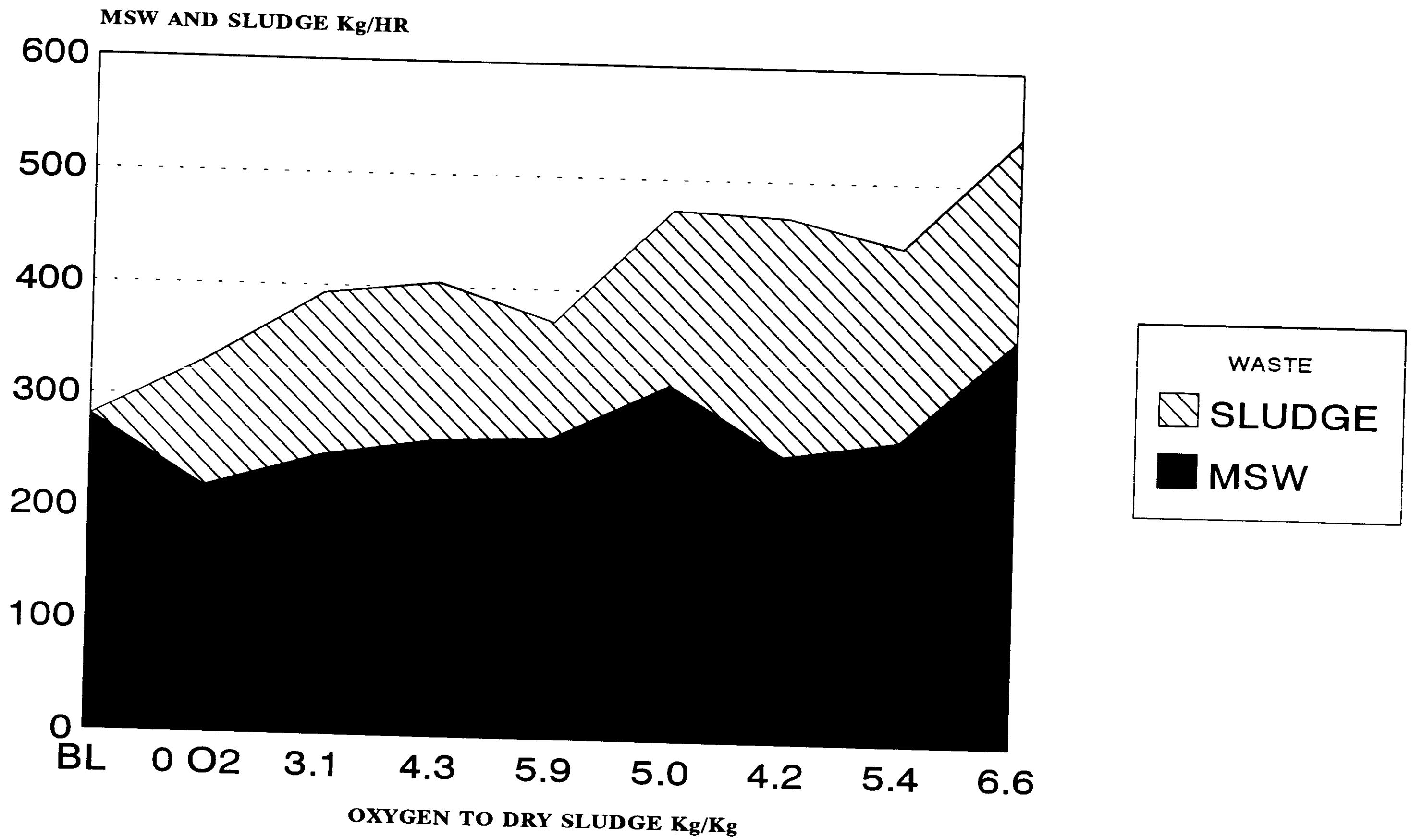
ALL FLOWS NORMALIZED TO 8.5% O2 IN THE FLUE GAS
ALL FLOWS NORMALIZED TO A FLUE GAS FLOW OF 5000 LB/HR

FIGURE 5B. CUMULATIVE MSW AND SLUDGE PROCESSING CAPACITY (U.S. UNITS)
AS A FUNCTION OF OXYGEN ADDITION PHASE 1
NORMALIZED RESULTS

TABLE 8. NORMALIZED PILOT PLANT DATA

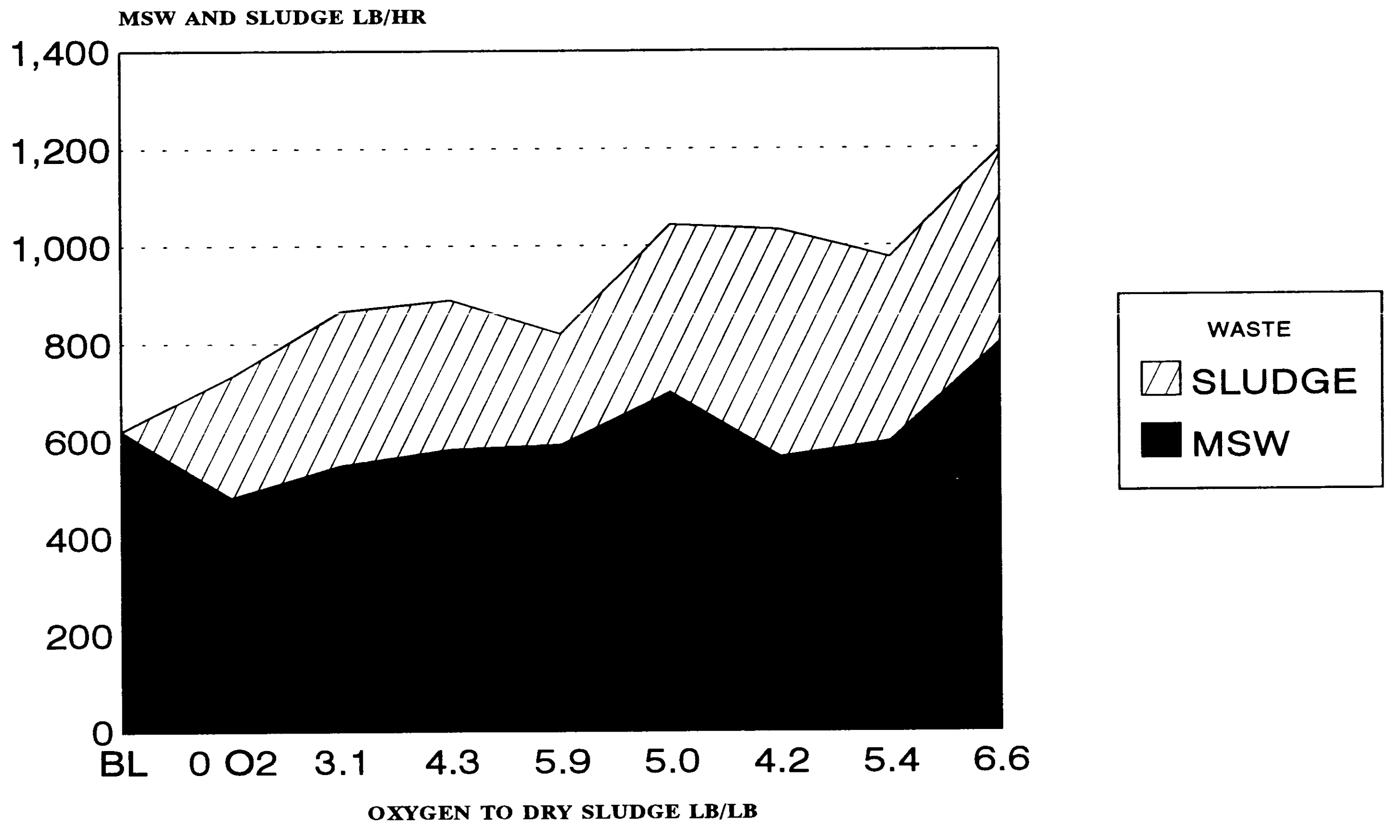
RUN NO.	FLUE GAS O2 (%)	O2/DRY SLUDGE Kg/Kg (lb/lb)	MSW SLUDGE/MSW (%)	FLUE GAS (lbmol/hr)	1ST PASS TEMP (C)	1ST PASS TEMP (F)	FLUE GAS @ 8.5% O2 (lbmol/hr)	1ST PASS TEMP @ 8.5% O2 (C)	1ST PASS TEMP @ 8.5% O2 (F)
Baseline:									
7A	8.6			170	823	1513	168.5	833	1531
8A	7.4			180	835	1535	196	742	1368
13A	8.3			153	849	1561	155.5	831	1528
14A	9.0			168	823	1514	161	873	1603
20	8.6			169	872	1601	167.5	882	1619
22A	7.7			171	849	1560	181.6	783	1441
23A	8.3			181	909	1669	184	891	1636
24A	8.2			171	872	1602	175	846	1555
Average				170	854	1,569	174	835	1,535
Coincineration:									
16C	8.1		3.3	153	812	1494	158	776	1429
22B	5.8		5.1	176	874	1605	214	673	1243
26B	6.8		11.3	178	876	1608	202.2	740	1364
Average				169	854	1569	191	729	1,345
O2 Enriched Coincineration									
16A	8.3	4.3	4.0	162	804	1480	164.5	787	1449
16B	8.7	6.6	3.8	154	857	1574	151.9	872	1602
17B	8.7	4.2	4.5	158	811	1491	155.5	829	1524
22C	8.0	5.9	5.8	176	917	1683	183	875	1605
23B	6.2	4.3	8.2	182	959	1759	215.5	783	1442
23C	5.6	3.1	8.7	173	964	1767	209	769	1416
24B	8.1	5.4	9.5	171	941	1725	176.5	905	1661
24C	8.0	4.2	11.0	182	911	1671	189.3	867	1592
25B	7.6	5.0	7.2	183	918	1684	196.2	842	1547
25C	9.0	6.6	6.6	178	893	1640	171	940	1724
Average				172	897	1,647	181	847	1556

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



ALL FLOWS NORMALIZED TO 8.5% O2 IN THE FLUE GAS
ALL FLOWS NORMALIZED TO A FLUE GAS FLOW OF 2268 Kg/HR

FIGURE 6A. CUMULATIVE MSW AND SLUDGE PROCESSING CAPACITY (METRIC)
AS A FUNCTION OF OXYGEN ADDITION PHASE 2
NORMALIZED RESULTS



ALL FLOWS NORMALIZED TO 8.5% O2 IN THE FLUE GAS
ALL FLOWS NORMALIZED TO A FLUE GAS FLOW OF 5000 LB/HR

FIGURE 6B. CUMULATIVE MSW AND SLUDGE PROCESSING CAPACITY (U.S. UNITS)

AS A FUNCTION OF OXYGEN ADDITION PHASE 2
NORMALIZED RESULTS

TABLE 9. PILOT TEST FLUE GAS EMISSIONS SUMMARY

PHASE I	UNIT	BASELINE	O2 ENRICHED MSW INCINERATION				O2 ENRICHED COINCINERATION
O2 Enrichment Zone(1) Oxygen, mole %			Comb 23.7−24.3	Comb 26.6−27.1	Comb/OFA 27.0/25.4	OFS 25.1	Comb 24.9−26.5
O_2, average	%	9.7	10.6	11.2	11.6	10.2	10.5
CO_2, average	%	9.8	10.3	11.0	11.3	10.0	10.7
CO, average @ 7% O_2 (2)	ppm	152	101	111	103	104	235
NO_x, average @ 7% O_2	ppm	251	285	328	334	262	246
SO_2, average @ 7% O_2	ppm	157	179	232	308	109	202
HC, average @ 7% O_2	ppm	4.7	3.0	7.7	3.7	0.6	15.8
HCl, average @ 7% O_2	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	**UNIT**	**BASELINE**	**COINCINERATION WITHOUT O2**	**O2 ENRICHED COINCINERATION**			
O2 Enrichment Zone(1) Oxygen, mole %				OFA 34.1−43.7	Sludge Gun		
O_2, average	%	9.6	8.0	9.5	11.3		
CO_2, average	%	9.7	11.2	13.4	13.1		
CO, average @ 7% O_2 (2)	ppm	104	146	83	121		
NO_x, average @ 7% O_2	ppm	211	162	283	355		
SO_2, average @ 7% O_2	ppm	103	137	201	145		
HC, average @ 7% O_2	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,23−24B/C	25B,25C		

NOTES:
(1) Comb = Combustion Zone of Underfire Air, OFA = Overfire Air, Sludge Gun = Sludge Atomization Nozzle
(2) CO data corrected, > 800ppm CO (measured) was deleted due to furnace excursions.

Consequently, even though MSW and sludge were successfully co-incinerated without oxygen enrichment, there were effects on operating conditions which adversely affected flue gas emissions by increasing the concentrations of CO and total hydrocarbon.

Oxygen-Enriched Co-Incineration of MSW and Sewage Sludge--

Ten runs (16A, 16B, 17A, 22C, 23B, 23C, 24B, 24C, 25B, and 25C) were conducted with sludge co-incinerated with MSW and oxygen enrichment. Table 8 indicated that with oxygen concentration normalized to 8.5 percent (wet) in the flue gas, average first-pass temperatures were 835°C (1,535°F) for baseline runs and 847°C (1,556°F) for oxygen-enriched co-incineration, indicating an ability to maintain temperature stability.

Figures 7A (metric units) and 7B (U.S. units), developed by APCI, plot normalized first-pass temperatures against oxygen requirements in pounds per dry pound of sludge, and estimated that to maintain an average-base first-pass temperature of 835°C (1,535°F), as established during the baseline runs, approximately 3.5 to 5.5 kilograms (pounds) of oxygen per kilogram (pound) of dry sludge would be required. This is a reasonable estimate based on the limited testing performed, however the range is very broad. Figures 6A and 6B showed the effect of oxygen enrichment on co-incineration of MSW and sewage sludge. Sludge was co-incinerated with MSW up to a maximum ratio of 11.3 percent dry sludge per pound of MSW.

Phase I and Phase II

Bottom and Fly Ash--

Bottom and fly ash was sampled and analyzed throughout the pilot demonstration program. Table 10 presents the results of these analyses.

The effects of oxygen-enriched incineration of MSW and co-incineration of MSW and sewage sludge do not appear to have a significant effect on the heavy metal content of the ash product. Lead content had the most variability and it was most likely a function of the lead content of the MSW itself.

Hydrochloric Acid--

Flue gas HCl concentrations were measured during Phase I of the pilot test program and ranged from approximately 250 to 400 ppm when measured in the untreated flue gas.

The results of the measurements were plotted against the first pass temperature and are presented in Figure 8.

The data is scattered with little or no apparent correlation to first-pass temperature. However, test runs performed on the same day have similar levels of HCl concentrations (i.e., 13B and 13C and 14B and 14C) suggesting that flue gas HCl concentrations are more a function of the chlorine content of MSW and/or sewage sludge.

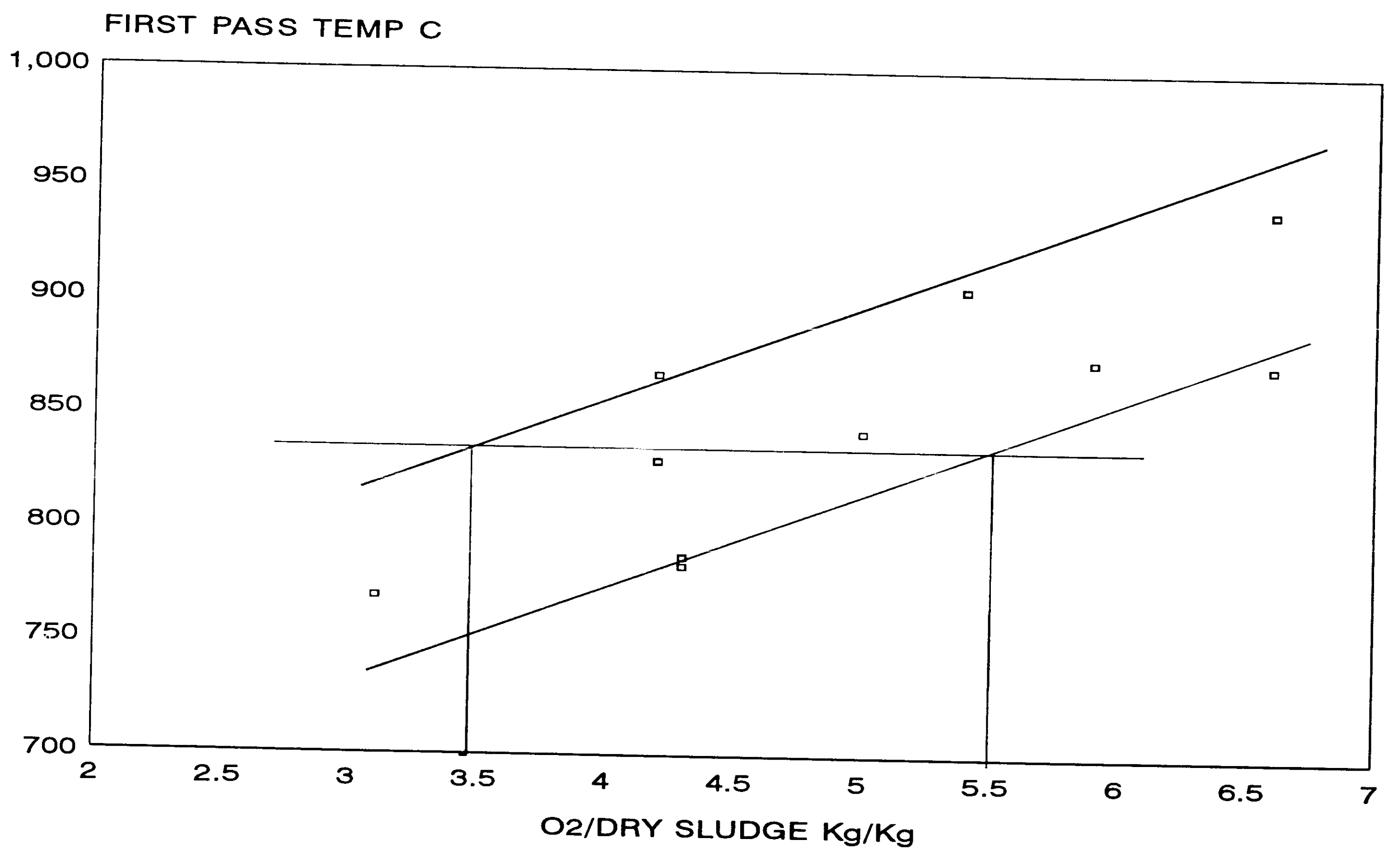


FIGURE 7A. OXYGEN USAGE FOR MSW AND SEWAGE SLUDGE COINCINERATION (METRIC UNITS)

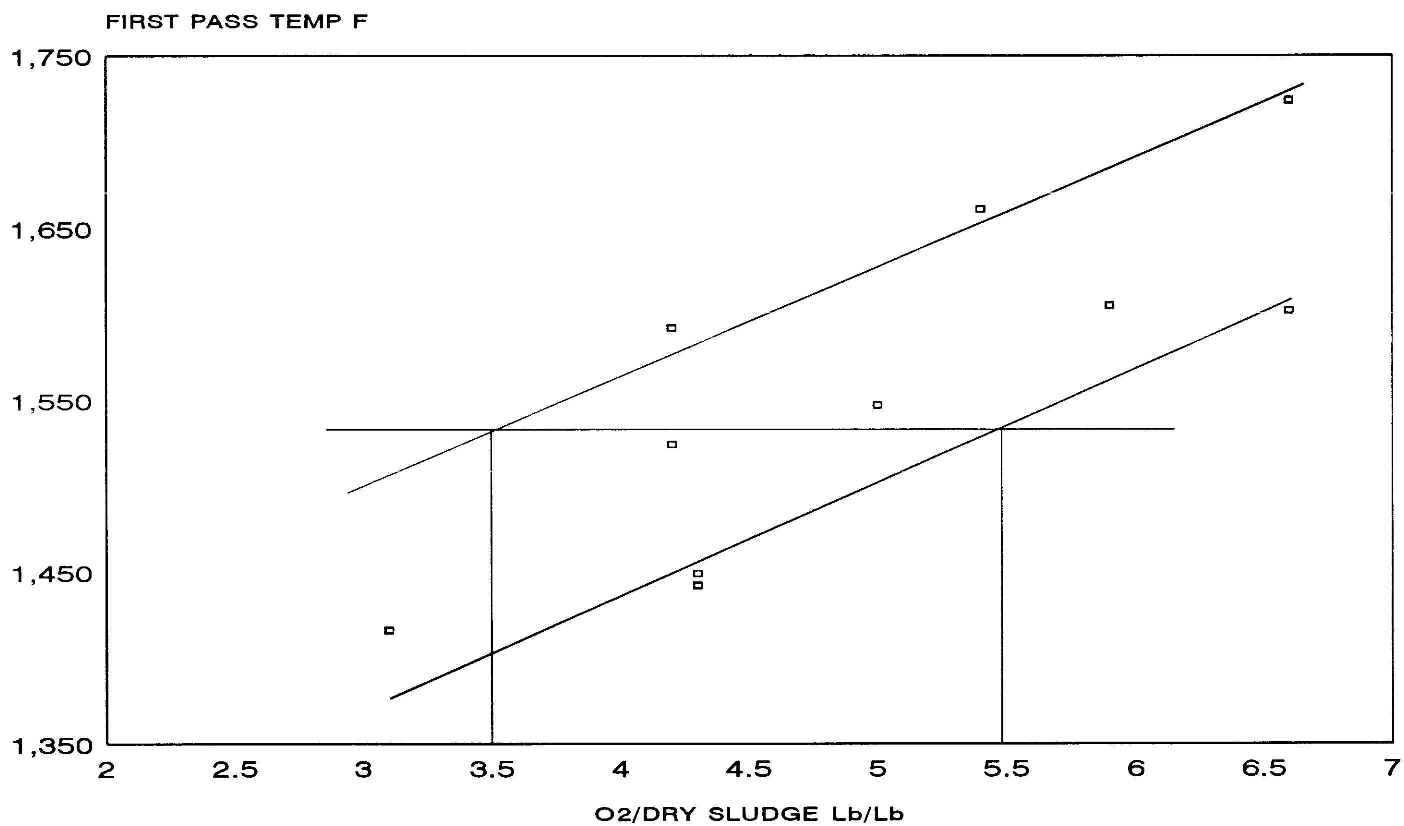


FIGURE 7B. OXYGEN USAGE FOR MSW AND SEWAGE SLUDGE COINCINERATION (U.S. UNITS)

TABLE 10. BOTTOM ASH/FLY ASH SUMMARY – PHASE I/PHASE II

Phase		Detection Limit	Method Reference	Baseline	O2 Enriched MSW Incineration				Oxygen Enriched Coincineration
O2 Enrichment Zone(2)					Comb	Comb	Comb/OFA	OFA	Comb
Oxygen, mole %					26.6 – 27.1	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 CA	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
Sulfur (water extractable)	ppm	150	9036	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 CA	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
Sulfur (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

(continued)

Table 7–4 from APCI Report

Table 10. Continued

Phase II		Detection Limit	Method Reference(1	Baseline	Coincineration without O2	Oxygen-Enriched Coincineration
O2 Enrichment Zone(2)						
Oxygen, mole %						
Bottom Ash:						
Arsenic as As	ppm	10	6010	BDL	BDL	BDL
Barium as Ba	ppm	25	6010	435	475	447
Cadmium as CA	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
Sulfur (water extractable)	ppm	150	9036	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 CA	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
Sulfur (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,23,24,25B/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 8. HYDROCHLORIC ACID (HCl) EMMISSIONS

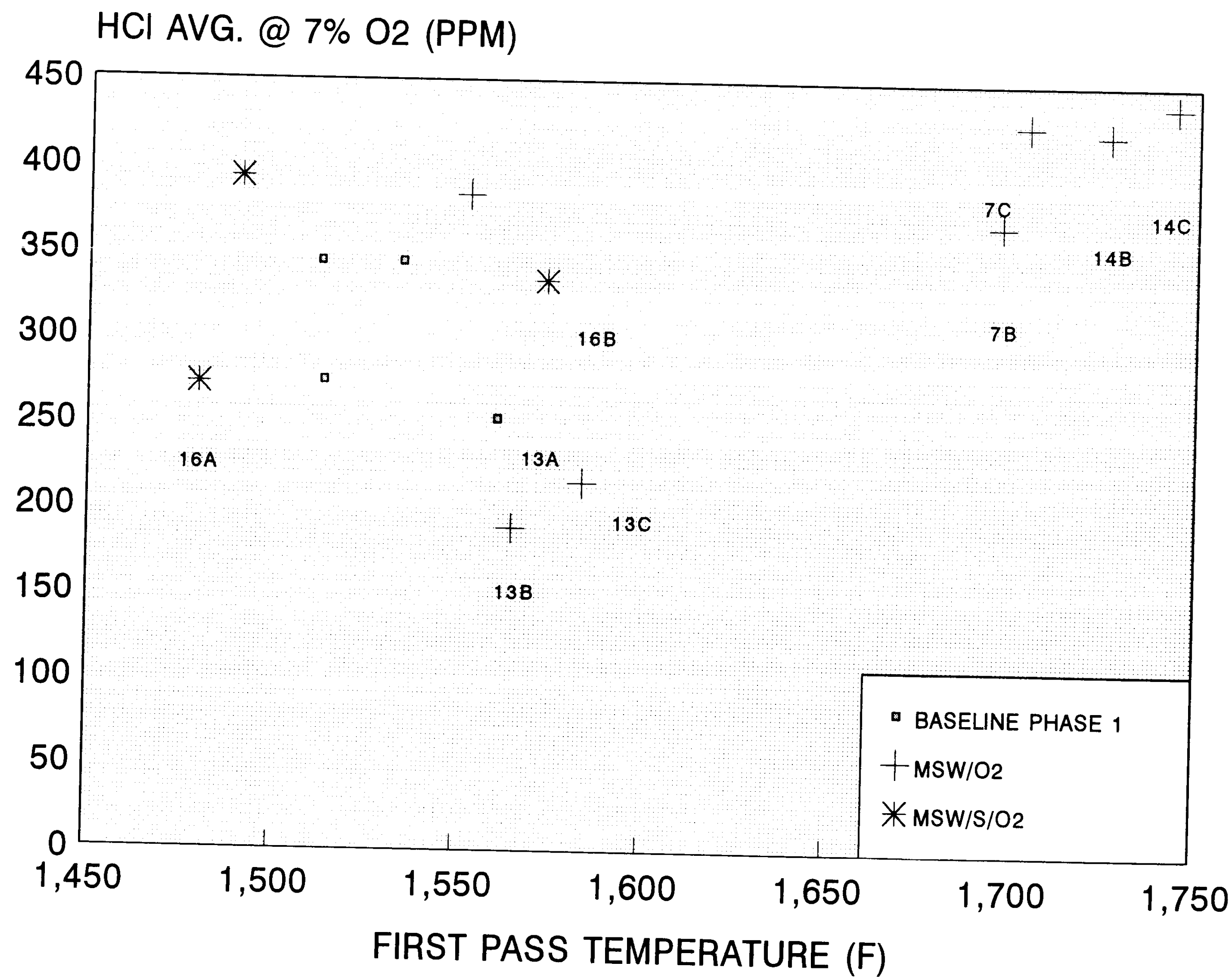


FIGURE 7-11 FROM APCI FINAL REPORT

Total Hydrocarbons--

As was shown on Table 9, co-incineration in conjunction with O_2-enrichment could result in higher uncontrolled emission of hydrocarbons than typically experienced with MSW incineration. Additionally, as shown on Figure 8A, which provides a hydrocarbon emissions trend for run 26B (co-incineration without oxygen enrichment) conducted during Phase II, hydrocarbon emissions can be dramatically affected by upsets in incinerator operation.

INDEPENDENT VERIFICATION OF TEST RESULTS

Theoretical Comparison of Reported Results

In order to provide a review and verification of the results reported in the APCI final report, the corrected heat and material balance program (developed by APCI) results for each test run were checked by CSI using a theoretical combustion calculation. Appendix B contains the combustion calculation results for each run. The corrected MSW ultimate analysis, produced by the heat and material balance program, the sludge ultimate analysis obtained from laboratory analysis, and the actual MSW and sludge throughputs were utilized, and the excess air and oxygen concentration was varied until the corrected flue gas moisture concentration, oxygen concentration, and actual flue gas CO_2 concentrations were replicated. The flue gas and oxygen-flow rates were then compared for consistency to the reported results. Tables 11A (metric units) and 11B (U.S. units) compare the reported results to the theoretical results for the Phase I testing, and Tables 12A (metric units) and 12B (U.S. units) compare the reported results to the theoretical results for the Phase II testing.

As noted, the data compared very favorably with flue-gas flow in most cases, i.e., within 1 to 2 percent, and in a few cases in excess of 3 percent. In all cases, the theoretical oxygen flow rates were higher than the reported rates, and the differential ranged from a low of .91 kg/hr (2 lbs/hr) to a high of 15.42 kg/hr (34 lbs/hr), with an average of 7.26 kg/hr (16 lbs/hr). As an alternative comparison, Run 24C, which showed the highest oxygen-flow differential [15.42 kg/hr (34 lbs/hr)] was checked using a theoretical combustion calculation, as previously discussed, except that oxygen concentration was varied ntil the reported oxygen flow rate was replicated. Theoretical flue gas, O_2, CO_2, and H_2O concentrations were compared to APCI's reported results, and in all cases the differential was less than 3 percent.

Conclusion

The reported results of each APCI test have been verified by CSI, using an alternative theoretical approach which yielded comparative differentials of less than 3 percent. It can therefore be concluded that APCI's reported results accurately reflect the outcome of the limited pilot-scale demonstrating program that was performed.

FIGURE 8A. FLUE GAS HYDROCARBON EMISSION TREND

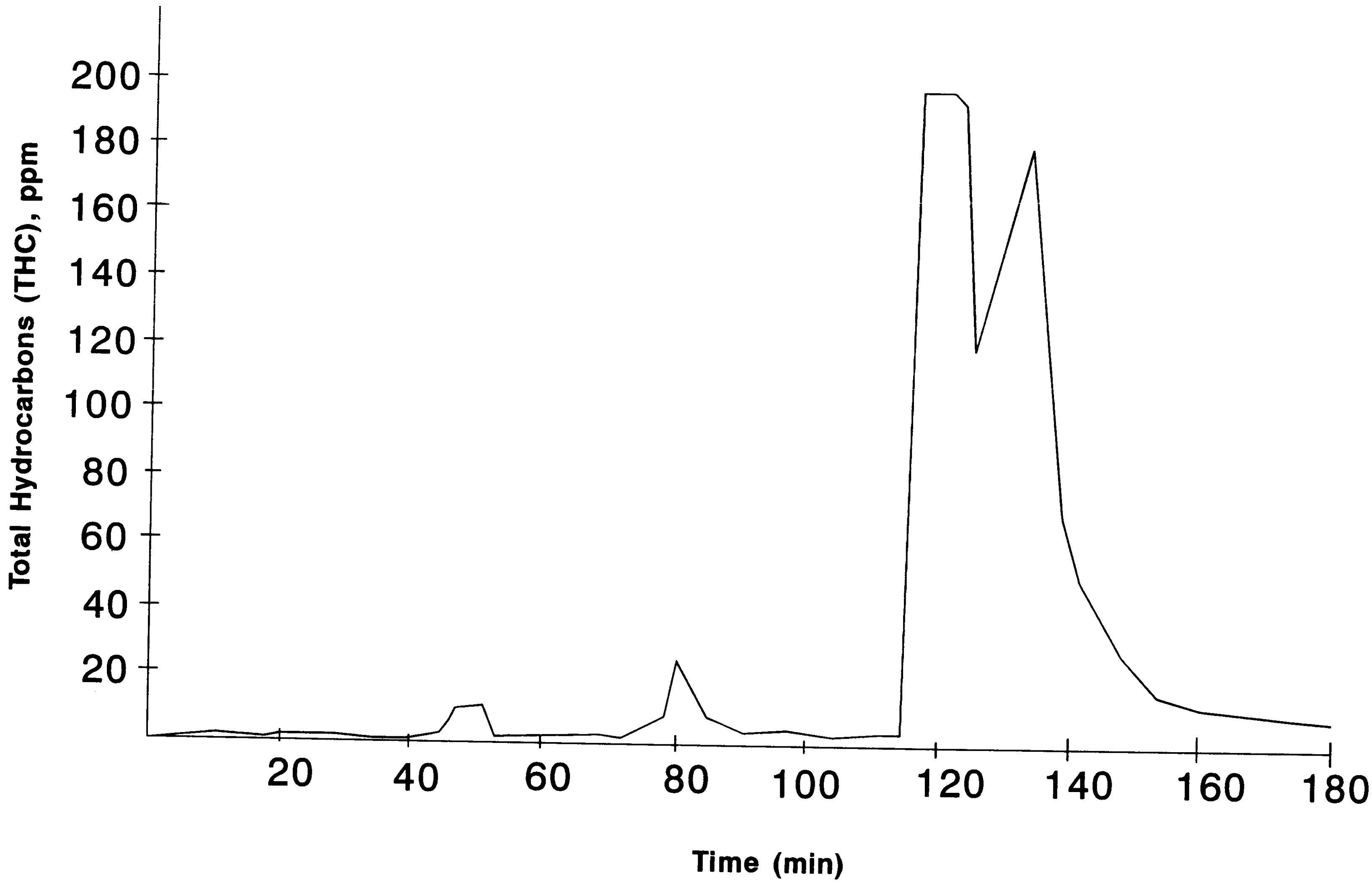


Figure 7-12 from APCI Report

TABLE 11A. PHASE I – COMPARISON OF CORRECTED APCI RESULTS TO THEORETICAL RESULTS (METRIC)

	7A APCI	7A THEOR.	8A APCI	8A THEOR.	13A APCI	13A THEOR.	14A APCI	14A THEOR.
WASTE Kg/HR	273	273	303	303	244	244	263	263
SLUDGE Kg/HR	0	0	0	0	0	0	0	0
OXYGEN Kg/HR	0	0	0	0	0	0	0	0
FLUE GAS Kg/HR	2177	2200	2177	2215	2150	1989	2150	2172
O2 DRY %	10	10	8.8	8.8	9.6	9.6	10.5	10.5
O2 WET %	8.6	8.59	7.4	7.44	8.3	8.34	9	9.01
CO2 DRY %	9.4	9.41	10.6	10.52	10.1	10.05	8.9	8.89
H2O %	14.1	14.15	15.4	15.45	13.2	13.15	14.2	14.2

	7B APCI	7B THEOR.	7C APCI	7C THEOR.	9A APCI	9A THEOR.	13B APCI	13B THEOR.	13C APCI	13C THEOR.	14B APCI	14B THEOR.	14C APCI	14C THEOR.
WASTE Kg/HR	307	307	318	318	266	266	256	256	287	287	327	327	323	323
SLUDGE Kg/HR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OXYGEN Kg/HR	38	45	75	76	23	25	38	40	75	78	75	80	98	106
FLUE GAS Kg/HR	2359	2403	2341	2365	1950	1960	2168	2181	2291	2292	2223	2256	2200	2224
O2 DRY %	10	10	10.7	10.74	10.2	10.25	11.2	11.2	12.1	12.1	10.9	10.9	11.6	11.6
O2 WET %	8.6	8.58	9.2	9.26	8.6	8.67	9.8	9.78	10.5	10.53	9.1	9.06	9.7	9.68
CO2 DRY %	10.7	10.71	11.7	11.64	10	10	9.8	9.79	10.4	10.42	10.9	10.85	11.3	11.29
H2O %	14.1	14.22	13.7	13.75	15.3	15.36	12.7	12.71	12.9	12.98	16.9	16.88	16.6	16.56

	16A APCI	16A THEOR.	16B APCI	16B THEOR.	17B APCI	17B THEOR.
WASTE Kg/HR	264	264	240	240	238	238
SLUDGE Kg/HR	59	59	59	59	77	77
OXYGEN Kg/HR	45	54	60	68	45	50
FLUE GAS Kg/HR	2043	2056	1950	1977	1987	2024
O2 DRY %	10.3	10.3	10.6	10.6	10.7	10.7
O2 WET %	8.3	8.32	8.7	8.65	8.7	8.69
CO2 DRY %	10.6	10.6	11	11	10.4	10.4
H2O %	19.1	19.2	18.3	18.35	18.9	18.8

TABLE 11B. PHASE II – COMPARISON OF CORRECTED APCI RESULTS TO THEORETICAL RESULTS (U.S. UNITS)

	20 APCI	20 THEOR.	22A APCI	22A THEOR.	23A APCI	23A THEOR.	24A APCI	24A THEOR.
WASTE LB/HR	575	575	636	636	629	629	649	649
SLUDGE LB/HR	0	0	0	0	0	0	0	0
OXYGEN LB/HR	0	0	0	0	0	0	0	0
FLUE GAS LB/HR	4712	4755	4740	4885	5025	5109	4750	4854
O2 DRY %	10	9.99	9	9	9.8	9.8	9.7	9.69
O2 WET %	8.6	8.59	7.7	7.74	8.3	8.32	8.2	8.23
CO2 DRY %	9.4	9.39	10.4	10.37	9.3	9.3	9.6	9.59
H2O %	14	14.02	14	14.01	15	15.09	15	15.04

	22B APCI	22B THEOR.	26B APCI	26B THEOR.
WASTE LB/HR	616	616	552	552
SLUDGE LB/HR	235	235	370	370
OXYGEN LB/HR	0	0	0	0
FLUE GAS LB/HR	4900	4938	5300	5278
O2 DRY %	7.3	7.29	8.6	8.6
O2 WET %	5.8	5.83	6.8	6.75
CO2 DRY %	11.8	11.77	10.6	10.58
H2O %	20*	19.97	21.5	21.46

	22C APCI	22C THEOR.	23B APCI	23B THEOR.	23C APCI	23C THEOR.	24B APCI	24B THEOR.
WASTE LB/HR	610	610	697	697	641	641	583	583
SLUDGE LB/HR	235	235	370	370	370	370	370	370
OXYGEN LB/HR	210	234	244	262	171	181	302	335
FLUE GAS LB/HR	4900	4925	5050	5016	4803	4642	4758	4712
O2 DRY %	10	10	8.4	8.4	7.6	7.6	10.8	10.8
O2 WET %	8	7.94	6.2	6.23	5.6	5.54	8.1	8.08
CO2 DRY %	12.3	12.3	14.6	14.6	14	14	13.3	13.3
H2O %	20.5	20.6	26	25.89	26.6	27.08	25	25.21

	24C APCI	24C THEOR.	25B APCI	25B THEOR.	25C APCI	25C THEOR.
WASTE LB/HR	591	591	752	752	750	750
SLUDGE LB/HR	490	490	370	370	370	370
OXYGEN LB/HR	272	306	272	302	328	350
FLUE GAS LB/HR	5050	4998	5100	5001	4950	4890
O2 DRY %	10.9	10.9	10.4	10.4	12.2	12.2
O2 WET %	8	7.96	7.6	7.64	9	8.98
CO2 DRY %	12.7	12.7	13.1	13.1	13	13
H2O %	27	26.94	26.5	26.58	26.5	26.43

* ESTIMATED.

TABLE 12A. PHASE II – COMPARISON OF CORRECTED APCI RESULTS TO THEORETICAL RESULTS (METRIC UNITS)

	20 APCI	20 THEOR.	22A APCI	22A THEOR.	23A APCI	23A THEOR.	24A APCI	24A THEOR.
WASTE Kg/HR	261	261	288	288	285	285	294	294
SLUDGE Kg/HR	0	0	0	0	0	0	0	0
OXYGEN Kg/HR	0	0	0	0	0	0	0	0
FLUE GAS Kg/HR	2157	2157	2150	2216	2279	2317	2155	2202
O2 DRY %	10	9.99	9	9	9.8	9.8	9.7	9.69
O2 WET %	8.6	8.59	7.7	7.74	8.3	8.32	8.2	8.23
CO2 DRY %	9.4	9.39	10.4	10.37	9.3	9.3	9.6	9.59
H2O %	14	14.02	14	14.01	15	15.09	15	15.04

	22B APCI	22B THEOR.	26B APCI	26B THEOR.
WASTE Kg/HR	279	279	250	250
SLUDGE Kg/HR	107	107	168	168
OXYGEN Kg/HR	0	0	0	0
FLUE GAS Kg/HR	2223	2240	2404	2394
O2 DRY %	7.3	7.29	8.6	8.6
O2 WET %	5.8	5.83	6.8	6.75
CO2 DRY %	11.8	11.77	10.6	10.58
H2O %	20*	19.97	21.5	21.46

	22C APCI	22C THEOR.	23B APCI	23B THEOR.	23C APCI	23C THEOR.	24B APCI	24B THEOR.	24C APCI	24C THEOR.	25B APCI	25B THEOR.	25C APCI	25C THEOR.
WASTE Kg/HR	277	277	316	316	291	291	261	264	268	268	341	341	340	340
SLUDGE Kg/HR	107	107	168	168	168	168	168	168	222	222	168	168	168	168
OXYGEN Kg/HR	95	106	111	119	78	82	137	152	123	139	123	137	149	159
FLUE GAS Kg/HR	2223	2234	2291	2275	2179	2106	2158	2137	2291	2267	2313	2268	2245	2218
O2 DRY %	10	10	8.4	8.4	7.6	7.6	10.8	10.8	10.9	10.9	10.4	10.4	12.2	12.2
O2 WET %	8	7.94	6.2	6.23	5.6	5.54	8.1	8.08	8	7.96	7.6	7.64	9	8.98
CO2 DRY %	12.3	12.3	14.6	14.6	14	14	13.3	13.3	12.7	12.7	13.1	13.1	13	13
H2O %	20.5	20.6	26	25.89	26.6	27.08	25	25.21	27	26.94	26.5	26.58	26.5	26.43

* ESTIMATED.

TABLE 12B. PHASE II – COMPARISON OF CORRECTED APCI RESULTS TO THEORETICAL RESULTS (U.S. UNITS)

	20 APCI	20 THEOR.	22A APCI	22A THEOR.	23A APCI	23A THEOR.	24A APCI	24A THEOR.
WASTE LB/HR	575	575	636	636	629	629	649	649
SLUDGE LB/HR	0	0	0	0	0	0	0	0
OXYGEN LB/HR	0	0	0	0	0	0	0	0
FLUE GAS LB/HR	4712	4755	4740	4885	5025	5109	4750	4854
O2 DRY %	10	9.99	9	9	9.8	9.8	9.7	9.69
O2 WET %	8.6	8.59	7.7	7.74	8.3	8.32	8.2	8.23
CO2 DRY %	9.4	9.39	10.4	10.37	9.3	9.3	9.6	9.59
H2O %	14	14.02	14	14.01	15	15.09	15	15.04

	22B APCI	22B THEOR.	26B APCI	26B THEOR.
WASTE LB/HR	616	616	552	552
SLUDGE LB/HR	235	235	370	370
OXYGEN LB/HR	0	0	0	0
FLUE GAS LB/HR	4900	4938	5300	5278
O2 DRY %	7.3	7.29	8.6	8.6
O2 WET %	5.8	5.83	6.8	6.75
CO2 DRY %	11.8	11.77	10.6	10.58
H2O %	20*	19.97	21.5	21.46

	22C APCI	22C THEOR.	23B APCI	23B THEOR.	23C APCI	23C THEOR.	24B APCI	24B THEOR.	24C APCI	24C THEOR.	25B APCI	25B THEOR.	25C APCI	25C THEOR.
WASTE LB/HR	610	610	697	697	641	641	583	583	591	591	752	752	750	750
SLUDGE LB/HR	235	235	370	370	370	370	370	370	490	490	370	370	370	370
OXYGEN LB/HR	210	234	244	262	171	181	302	335	272	306	272	302	328	350
FLUE GAS LB/HR	4900	4925	5050	5016	4803	4642	4758	4712	5050	4998	5100	5001	4950	4890
O2 DRY %	10	10	8.4	8.4	7.6	7.6	10.8	10.8	10.9	10.9	10.4	10.4	12.2	12.2
O2 WET %	8	7.94	6.2	6.23	5.6	5.54	8.1	8.08	8	7.96	7.6	7.64	9	8.98
CO2 DRY %	12.3	12.3	14.6	14.6	14	14	13.3	13.3	12.7	12.7	13.1	13.1	13	13
H2O %	20.5	20.6	26	25.89	26.6	27.08	25	25.21	27	26.94	26.5	26.58	26.5	26.43

* ESTIMATED.

SECTION 5

COMMERCIAL APPLICATION CONSIDERATIONS

TECHNICAL AND OPERATIONAL IMPLICATIONS

Existing Facilities

Application of an oxygen-enrichment system to an existing waste-to-energy facility for the purpose of sewage sludge co-incineration with MSW would require a major capital investment as well as facility modifications. These modifications would include, at a minimum:

- a sludge receiving and storage area, including storage tanks or pits, depending upon the solids content of the as-received sludge;
- sludge transfer equipment, including conveyors and/or pumps;
- sludge conditioning equipment, to provide for grinders, and water addition if necessary;
- positive-displacement sludge pumps for delivering sludge to the furnace;
- nozzles for delivering sludge into the furnace;
- air compressors for atomization of the sludge delivered to the furnace;
- boiler modifications to enable nozzles to be installed into the furnace properly; and
- siting and installation of an oxygen-production facility.

The majority of the necessary facility modifications can be made while the facility is operational. The only interface that would affect operations is the installation of the sludge atomization nozzles in the boiler wall, which could potentially be accomplished during one or more scheduled outages, thereby minimizing the impact on existing operations.

Prior to its commercial application, it is important that the oxygen-enrichment technology be demonstrated over a prolonged period of time so as to determine whether it has any negative impacts on the boiler and facility, such as:

- Increased fouling and erosion of superheater and boiler tubes.
- Operational problems that affect the facility's availability and, consequently, the ability to meet contract obligations.
- Corrosion problems associated with boiler duct work, air pollution control equipment, and stacks.
- Adverse operational problems with existing air pollution control equipment due to increased moisture content and pollutants.
- Need to add additional air pollution control equipment.
- Decrease in the facility's net power production, exclusive of the additional power required to produce oxygen.

New Facilities

Given that most vendors already have available to them technology designed for co-incinerating sewage sludge with MSW without detriment to MSW throughput and could provide it at the design stage for new facility applications, incorporation of an oxygen-enrichment system into a new facility would likely be unnecessary. These technologies, for the most part, require sludge to be dried prior to being introduced into the furnace. Some examples are as follows.

- American Ref-Fuel's co-incineration system, which utilizes Deutsche Babcock Analgen technology, includes a direct flash-dryer, a drying mill, interconnecting refractory-lined duct work, and sludge handling equipment. Flue gas is withdrawn from the first boiler pass at temperatures in excess of 857°C (1,600°F) and directed to the flash dryer above the drying mill. The sludge cake is introduced into the flash-dryer using saturated steam for atomization. From the contact chamber, the sludge is ground, dried to 90-percent solids, and injected into the furnace.
- Katy-Seghers' co-incineration system uses an indirect drying process whereby energy is transferred from the exhaust gases to an oil medium. The oil medium is pumped to a multi-tray dryer where the sludge is dried. The dried sludge is then directly mixed with refuse in the feed hoppers.
- Martin co-incineration technology requires minimal drying, and sludge is delivered into the furnace utilizing a twin-screw discharger that compresses the sludge before it is fed to a roller-spreader that spreads the material over the refuse bed.

In all these cases, the water vapor is introduced into the furnace to destroy odors. These vendors have had operational experience (foreign) with their systems and would likely need strong technical and economic incentives to depart from their designs and accommodate an oxygen-enrichment system.

Operational Considerations

The operational requirements of an oxygen-enrichment system on either an existing or new facility would require:

- additional labor for sludge receiving, handling, operation, and maintenance;
- additional equipment reserve funds for equipment replacement;
- interface with the oxygen-production facility;
- provisions for disposal of the additional ash generated by sludge combustion;
- operational considerations relative to modifications to the existing air pollution control equipment and;
- potential oxygen facility operational responsibilities.

ENVIRONMENTAL REGULATORY AND PERMITTING REQUIREMENTS

The U.S. EPA has promulgated rules and regulations which establish permitting requirements and performance standards applicable to both MSW and sewage sludge incinerators. The state agencies, for the most part, have essentially adopted these requirements, and standards of more stringent criteria, in their regulations. These federal and state regulations have been or will soon be revised to comply with the provisions of the Clean Air Act Amendments of 1991.

Described below are the current and anticipated environmental regulations that could potentially impose constraints or performance criteria on municipal incinerators designed to co-incinerate sewage sludge with MSW.

Permitting Requirements

Before initiating construction, the owner or operator of a new municipal incinerator must submit applications for several permits to either the EPA or responsible state agency. For a modified facility, the owner/operator may be required to submit an application for permit amendments to these agencies. In either case, the permit application must demonstrate compliance with performance standards applicable to the source category, as well as ambient air quality criteria in the vicinity of the source. The applicable permitting requirements are contained in the following federal and state regulations:

- Prevention of Significant Deterioration regulations;

- Nonattainment Area regulations; and
- state air and solid waste regulations.

These regulations are discussed below in the context of municipal incinerators designed to burn sewage sludge in combination with MSW.

Prevention of Significant Deterioration Regulations--

According to the Prevention of Significant Deterioration (PSD) regulations, the owner/operator of a "major" source located in an attainment or unclassified area must obtain a PSD permit before initiating construction. For a modified major source, the owners/operators would be required to obtain a PSD permit if the modification resulted in a "significant" increase in the emissions of any pollutant regulated under the Clean Air Act. A significant emissions increase is defined by the de minimis emission rates issued by the EPA. A major stationary source is defined in the PSD regulations as any source included in a list of 28 specified categories with the potential to emit 90.7 tonnes (i.e., metric tons) per year (100 TPY) of any regulated pollutant. These 28 source categories include municipal incinerators with an aggregate capacity greater than 227 tonnes per year (250 TPY).

The owner/operator of a modified major source must meet the following requirements in accordance with the PSD regulations:

- apply Best Available Control Technology (BACT) for all regulated pollutants emitted in significant quantities;

- assess ambient air quality in the vicinity of the source using representative data from either a preconstruction monitoring program or an existing monitoring station;

- demonstrate compliance with ambient air quality standards and PSD allowable increments following operation of the modified source; and

- analyze the effects of source operation on soils, vegetation, and visibility, and the impacts of secondary growth in the vicinity of the source.

A source located within a nonattainment (NA) area for a given criteria pollutant is exempt from the PSD regulations; rather, the source may be subject to the NA Area regulations for that pollutant.

A municipal waste incinerator [greater than 227 tonnes per day (250 TPD) total MSW throughput] invariably emits more than 90.7 tonnes per year (100 TPY) of several regulated pollutants and thus is classified as a major source under the PSD regulations. Accordingly, a new municipal incinerator would be required to obtain a PSD permit prior to construction whether or not it is designed to burn sewage sludge with MSW. A modified facility could also be required to obtain a PSD permit if co-incineration results in a significant increase in the emission rate of any regulated pollutants. As was shown on Table 9, co-incineration in conjunction with O_2-enrichment could result in higher uncontrolled emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and hydrocarbons (HC) than typically experienced with MSW incineration. Co-incineration could also result in higher uncontrolled emissions of certain trace metals and, possibly, semi-volatile organic compounds, depending on the combustion conditions and sewage sludge composition. The controlled emissions from new facilities, however, should be similar to those associated with MSW incineration, because of the mandated air pollution control systems for new municipal waste combustors (i.e., combustion controls, selective noncatalytic reduction, spray dryer absorbers, and baghouses). For modified facilities, co-incineration with O_2-enrichment would likely result in a significant increase in NO_x emissions, since existing facilities may not incorporate selective noncatalytic reduction (SNCR) for NO_x control. This significant increase in NO_x emissions would trigger a PSD permit for the necessary modifications.

Nonattainment Area Regulations--
The owner or operator of a major source of a given criteria pollutant, which is located in an NA area for that pollutant, must meet the requirements of the NA Area regulations. For a modified major source, the owners/operators are subject to these requirements if the modification results in a "significant" increase in the emissions of the subject pollutant (see Table 13). A major source is defined in the NA Area regulations as one that emits more than 90.7 tonnes per year (100 TPY) of the subject pollutant. The Clean Air Act Amendments of 1991, however, revise the definition of a major source of volatile organic compounds (VOC) depending on the classification of the NA area -- a source emitting 90.7 tonnes per year (100 TPY) in marginal or moderate areas, 45.4 tonnes per year (50 TPY) in serious areas, 22.7 tonnes per year (25 TPY) in severe areas, and 9.1 tonnes per year (10 TPY) in extreme areas.

According to the NA Area regulations, the owner/operator of a modified major source must meet the following requirements:

- comply with Lowest Achievable Emission Rate (LAER) for that source category;
- obtain contemporaneous emission offsets for the subject criteria pollutant;
- demonstrate a net air quality benefit for that pollutant in the vicinity of the source; and
- ensure that all sources owned by the applicant within the state comply with applicable regulations.

Again, a municipal waste incinerator [greater than 227 TPY tonnes per year (250 TPY) total MSW throughput] typically emits more than 90.7 TPY tonnes per year (100 TPY) of particulates, SO_2, NO_x, and CO. Accordingly, a new facility located in an NA area for these pollutants would be required to comply with the LAER, emissions offset, net air quality benefit, and other requirements of the NA Area regulations. For modified facilities, the existing air pollution control systems would likely maintain particulate, SO_2, and CO at their current levels,

TABLE 13. EXISTING AND EXPECTED SECTION III(d) EMISSION GUIDELINES APPLICABLE TO EXISTING MUNICIPAL WASTE COMBUSTORS [greater than 227 tonnes per day (250 TPD)]*

POLLUTANT	UNITS	EMISSION GUIDELINES		
		Existing Guidelines†		Expected Guidelines
		Large Plants	Very Large Plants	
Particulate Matter	gr/dscm @ 7% O_2	1.059	0.530	0.530
	(gr/dscf @ 7% O_2)	(0.030)	(0.015)	(0.015)
Visible Emissions	% opacity	10	10	10
SO_2	% reduction	50	70	80
	ppmdv @ 7% O_2	30	30	30
HCl	% reduction	50	90	95
	ppmdv @ 7% O_2	25	25	25
CO	ppmdv @ 7% O_2	50-250	50-250	50-250
PCDD/PCDF	ng/dscm @ 7% O_2	125-250	60	30
Pb	ug/dscm @ 7% O_2	-	-	160-500‡
Cd	ug/dscm @ 7% O_2	-	-	20-40‡
Hg	% reduction	-	-	80‡
	ug/dscm @ 7% O_2	-	-	100‡

* Existing guidelines issued on February 11, 1991; expected guidelines issued in July 1992.

† Large plants are >227 TPD metric (250 TPD), but ≤ 1,000 TPD metric (1,100 TPD); very large plants are > 1,000 TPD metric (1,100 TPD).

‡ Either the lower Pb and Cd limits with no Hg limit or the higher Pb and Cd limits plus Hg limits.

thus precluding a significant increase in these pollutant emissions. In the absence of SNCR (Selective Non-Catalytic Reduction), however, the modifications could result in a significant increase in NO_x emissions and would trigger review under the NA Area regulations for that pollutant.

State Air and Solid Waste Regulations--
The various state agencies have also promulgated regulations establishing performance standards and permitting processes for municipal incinerators capable of co-incinerating sewage sludge in combination with MSW. The performance standards represent the minimum performance criteria for the air pollution control systems applied to the facility. In addition, they must be at least as stringent as the emission limit specified in the applicable federal standards and guidelines established by EPA. The applicable federal standards and guidelines are discussed in the next section.

The permitting processes allow for a comprehensive review of the proposed action in order to develop source-specific control technology requirements and associated performance levels. The state regulatory agency would definitely require an air permit for a new municipal incinerator. For a modified source, the state agency would typically review the air permit for an existing municipal incinerator and, if necessary, would require a permit amendment before allowing the operator to incinerate sewage sludge at the modified facility. Depending on the state, the permit application should also satisfy the requirements of the PSD and NA Area regulations. The review of the permit application could be a lengthy process and would typically entail providing public notice and holding public hearings on the proposed modifications.

For new municipal incinerators, a solid waste permit would also be required to allow the operator to receive and process sewage sludge at the facility. A permit amendment would almost certainly be required for modification of an existing incinerator. The permit application typically would include process description, sewage sludge composition, plans, and specifications, operating and maintenance procedures, and other pertinent information. Similar to the air permit, the review process would typically entail public notice and hearings.

Performance Standards--
The EPA and state agencies have issued performance standards and emission guidelines that impose design and operational constraints on municipal incinerators. These include the following regulations:

- New Source Performance Standards and Section 111(d) Emission Guidelines; and

- National Emission Standards for Hazardous Air Pollutants.

Presented below are the performance standards and emission guidelines applicable to municipal incinerators modified to co-incinerate sewage sludge in combination with MSW. Note that the recently promulgated standards for sewage sludge incinerators (40 CFR 503, Subpart E) apply only to those "devices in which only sewage sludge and auxiliary fuel are fired." These standards, therefore, are not applicable to co-incineration facilities.

New Source Performance Standards--The New Source Performance Standards (NSPS) constitute a set of national emissions standards that apply to specific categories of new sources. Pursuant to Section 111(d) of the Clean Air Act, the EPA may also establish emission guidelines intended to assist state agencies in the development of standards for existing facilities. To date, the EPA has promulgated NSPS and/or emission guidelines applicable to municipal waste combustors and industrial boilers -- both would impose emission limits and operating requirements on co-incineration facilities.

Municipal Waste Combustors. On February 11, 1991, the EPA promulgated the NSPS for new municipal solid waste combustors (MSWCs) having a unit capacity greater than 227 TPD tonnes per day (250 TPD) (40 CFR 60, Subpart Ea). Coincidentally, the EPA promulgated Section 111(d) emission guidelines for existing MWCs (40 CFR 60, Subpart Ca). These standards and guidelines establish emission limits for MWC metals (measured as particulate matter), MWC organics (dioxins and furans), MWC acid gases (SO_2 and HCl), and nitrogen oxides (NO_x). They also specify minimum criteria for "good operating practices," operator certification, performance testing, continuous monitoring, and reporting and recordkeeping.

According to Section 129 of the 1990 Clean Air Act Amendments, the EPA is required to revise the NSPS and emission guidelines for MWCs with a capacity greater than 227 TPD tonnes per day (250 TPD) within 12 months of enactment of the amendments. However, the EPA has recently indicated that the revisions will not be proposed until June 1993. The amendments require that, at a minimum, numerical limitations be specified for particulate matter, opacity, SO_2, HCL, NO_x, CO, dioxins/furans (PCDD/PCDF), lead (Pb), cadmium (Cd), and mercury (Hg). Table 13 (presented previously) and Table 14 summarize the emission limitations specified in the existing and expected NSPS and emission guidelines, respectively.

As previously indicated, co-incineration with O_2-enrichment could result in higher uncontrolled emissions of SO_2, NO_x, and CO than found in MSW incineration. Depending on the combustion conditions and sewage sludge composition, co-incineration could also result in higher uncontrolled emissions of Pb, Cd, Hg, and possibly, PCDD/PCDF. Despite these potentially higher uncontrolled emission levels, the air pollution control systems required by the NSPS should ensure compliance of new facilities with the emissions limits for SO_2, NO_x, CO, Pb, Cd, Hg, and PCDD/PCDF. It should be noted that an increase in uncontrolled NO_x emissions could push the performance envelope of commercially available SNCR processes. For modified facilities, co-incineration with O_2-enrichment would likely result in an increase in uncontrolled NO_x emissions, which could necessitate the retrofit of SNCR to ensure compliance with permit conditions (the guidelines do not specify an NO_x emission limit). Likewise, an increase in CO emissions could require modification of the combustion control

TABLE 14. EXISTING AND EXPECTED NEW SOURCE PEFORMANCE STANDARDS APPLICABLE TO NEW MUNICIPAL WASTE COMBUSTORS [greater than 227 TPD metric (250 TPD)]*

POLLUTANT	UNITS	PERFORMANCE STANDARDS	
		Existing	Expected
Particulate Matter	gr/dscm @ 7% O_2 (gr/dscf @ 7% O_2)	0.530 (0.015)	0.530 (0.015)
Visible Emissions	% opacity	10	10
SO_2	% reduction ppmdv @ 7% O_2	80 30	80 30
HCl	% reduction ppmdv @ 7% O_2	95 25	95 25
NO_x	ppmdv @ 7% O_2	-	180
CO	ppmdv @ 7% O_2	50-150	50-150
PCDD/PCDF	ng/dscm @ 7%O_2	30	30
Pb	ng/dscm @ 7%O_2	-	160
Cd	ng/dscm @ 7%O_2	-	20
Hg	% reduction ug/dscm @ 7% O_2	- -	80 100

* Existing standards issued on February 11, 1991; possible revisions to the expected standards developed in July 1992.

system or installation of auxiliary burners to meet either the emission guidelines or permit conditions.

Industrial Boilers. The EPA promulgated the NSPS for Industrial-Commercial-Institutional Steam Generating Units (40 CFR 60, Subpart Db) on July 13, 1985. These standards apply to industrial boilers with heat inputs greater than 25.2 x 10^6 kilocalories/hr (100 MMBtu/hr). They limit the emission of particulate matter, SO_2, and NO_x from various types of industrial boilers burning both fossil and non-fossil fuels (including municipal solid waste). Because these NSPS are less stringent than those applicable to MWCs, a new or modified facility would be required to comply with the MWC standards, rather than the industrial boiler standards, in accordance with EPA policy.

National Emission Standards for Hazardous Air Pollutants--The National Emission Standards for Hazardous Air Pollutants (NESHAP) are a set of emission standards that apply to both new and existing sources of hazardous air pollutants listed by the EPA. To date, the NESHAPs for beryllium and mercury are the only standards that may apply to existing MWCs burning sewage sludge in combination with MSW.

Beryllium. The NESHAP for beryllium (40 CFR 51, Subpart C) limit emissions from incinerators processing "beryllium-containing waste" to 10 grams over a 24-hour period. Alternatively, the EPA Administrator may allow the facility operator to meet an ambient beryllium concentration of 0.01 ug/m^3 average over a 30-day period. Beryllium-containing waste is defined in the standards as a material contaminated with beryllium and/or beryllium compounds used or generated during any process or operation performed by a source subject to this subpart (Subpart C). Because such waste is almost never processed in municipal incinerators, the NESHAP for beryllium generally are not applicable to these sources whether burning MSW alone or in combination with sewage sludge.

Mercury. The NESHAP for mercury (40 CFR 61, Subpart E) limit emissions from sewage sludge incineration and/or drying plants to 3,200 grams over any 24-hour period. The NESHAP also impose stack sampling and sludge analysis requirements on affected facilities. These standards would apply to municipal incinerators modified to burn sewage sludge in combination with MSW. Depending on the capacity of the MWC and the composition of the sewage sludge, mercury control (e.g., activated carbon injection) could be required on co-incineration facilities to ensure compliance with this NESHAP.

ECONOMIC IMPLICATIONS

CSI has estimated the potential costs of retrofitting an existing 680-tonne-per-day (750-TPD) waste-to-energy facility to co-incinerate municipal sewage sludge utilizing oxygen enrichment, based on preliminary budgetary capital and operating cost estimates developed by CSI. The costs of implementing a new oxygen-enriched co-incineration facility were not estimated, since, as discussed previously in this section, incorporating the APCI system would likely not enhance the technologies of, nor likely present an economic advantage to vendors of, state-of-the-art co-incineration facilities.

Four cases were evaluated (Table 15):

TABLE 15. CASES EVALUATED

CASES	MSW tonnes (tons)	WET SLUDGE tonnes (TPD) @ 15% solids)	OXYGEN/DRY SOLIDS Kg/Kg (lb/lb)	OXYGEN tonnes per day (TPD)
Case 1	680 (750)	181 (200)	1.59 (3.5)	95 (105)
Case 2	680 (750)	544 (600)	1.59 (3.5)	286 (315)
Case 3	680 (750)	181 (200)	2.49 (5.5)	150 (165)
Case 4	680 (750)	544 (600)	2.49 (5.5)	449 (495)

Capital Costs

Estimated capital costs for making waste-to-energy facility modifications so as to co-incinerate sludge with oxygen enrichment were based on recent quotations for new sludge co-incineration facilities and are as shown on Table 16.

TABLE 16. ESTIMATED FACILITY-RETROFIT CAPITAL COSTS:
181/544 METRIC TPD (200/600 TPD) OF WET SLUDGE
(15% solids)
($1993)

COST ELEMENT	181 METRIC TPD (200 TPD) ($000)	544 METRIC TPD (600 TPD) ($000)
Architectural & Engineering	$ 410	$ 880
Management Support & Activities	200	440
Site Work	270	580
Buildings	530	1,140
Equipment	4,500	9,700
Instrument & Control/Electrical	390	830
Boiler Modifications	500	1,000
Subtotal	6,800	14,570
Contingency @ 10%	680	1,460
TOTAL CAPITAL COSTS	$7,480	$16,030

Estimated capital costs for the oxygen-production facility necessary to supply the oxygen required are based on estimated costs from suppliers who furnish this type of facility and do not include any land acquisition costs. The costs are shown in Table 17.

TABLE 17. ESTIMATED OXYGEN-PRODUCTION FACILITY CAPITAL COSTS

FACILITY*	FACILITY COST ($000)
95 metric-TPD (105-TPD) Oxygen Production Facility	4,690
150 metric-TPD (165-TPD) Oxygen Production Facility	6,553
286 metric-TPD (315-TPD) Oxygen Production Facility	10,368
449 metric-TPD (495-TPD) Oxygen Production Facility	14,486

* Low-pressure oxygen at an oxygen purity of approximately 90%.

Operating and Maintenance Costs

Estimated additional costs to operate and maintain a waste-to-energy facility retrofitted to co-incinerate either 181 or 544 tonnes per day (TPD) of sludge are shown in Table 18.

The estimated additional operating and maintenance cost of an oxygen-production facility are shown in Table 19. These costs are based on estimated costs from suppliers of this type of facility and assume:

- 1,440 x 10^6 joules (400 kWh) consumed per ton of oxygen produced;
- an operating and maintenance labor force of six for a 272-tonne-per-day (300-TPD) oxygen facility (assume $40,000/year salary); and
- an allowance of approximately 1.75 percent of capital for equipment reserves.

Summary of Economic Analysis

As shown in Table 20, the first-year cost on a per-dry-tonne (per-dry-ton) basis varies from $353 to $452 per dry tonne ($320 to $410 per dry ton) for a 181-tonne (200-TPD) (wet) facility, and from $287 to $364 per dry tonne ($260 to $330 per dry ton) for a 544-tonne (600-TPD) (wet) facility, depending upon the amount of oxygen consumed. As discussed previously in this report, during the test runs, the amount of oxygen consumed varied from 3.5 to 5.5 kilograms (pounds) of oxygen per kilogram (pound) of sludge (at 15-percent solids). An

TABLE 18. RETROFITTED FACILITY ESTIMATED ADDITIONAL OPERATING AND MAINTENANCE COSTS: 181/544 METRIC TPD (200/600 TPD) OF WET SLUDGE (15% solids) ($1993)

COST ELEMENT	181 METRIC TPD (200 TPD)	544 METRIC TPD (600 TPD)
Labor*	$ 40,000	$ 80,000
Additional Maintenance and Service†	170,000	170,000
Equipment Reserve	131,000	281,000
Subtotal	341,000	531,000
Ash Disposal‡	130,000	390,000
Subtotal O&M	471,000	921,000
Contingency @ 10%	47,000	92,000
TOTAL O&M	$518,000	$1,013,000

* Assumes one person for 181 metric TPD (200 TPD), two persons for 544 metric TPD (600 TPD).

† The additional maintenance and service is 10 percent of the base facility maintenance and service cost in order to cover any additional costs associated with operating the facility, including sludge-handling equipment.

‡ Assumes $36.28/tonne ($40/ton), 28% ash, 20% moisture content.

TABLE 19. ESTIMATED ADDITIONAL OXYGEN-PRODUCTION FACILITY OPERATING AND MAINTENANCE COSTS ($1993)

COST ELEMENT	FACILITY SIZE [METRIC TPD (TPD)]			
	95 (105)	150 (165)	286 (315)	449 (495)
O&M	$ 80,000	$ 120,000	$ 240,000	$ 400,000
Equipment Reserve	80,000	110,000	180,000	250,000
Power	650,000	1,020,000	1,950,000	3,320,000
Subtotal O&M	$810,000	$1,250,000	$2,370,000	$3,970,000
Contingency @ 10%	81,000	125,000	237,000	397,000
TOTAL O&M	$891,000	$1,375,000	$2,607,000	$4,367,000

TABLE 20. SLUDGE TREATMENT AND DISPOSAL COSTS*
[$/dry/tonne ($/dry ton)]

CASE	SLUDGE PROCESSED @ 15% SOLIDS tonnes per day (TPD)	O_2 CONSUMPTION kg O_2/kg dry sludge (lb O_2/lb dry sludge)	OXYGEN tonnes per day (TPD)	SLUDGE TREATMENT AND DISPOSAL COST $/dry tonne ($/dry ton)
1	181 (200)	3.5	95 (105)	$353 ($320)
2	544 (600)	3.5	286 (315)	$287 ($260)
3	181 (200)	5.5	150 (165)	$452 ($410)
4	544 (600)	5.5	449 (495)	$364 ($330)

* Based on construction period of one year and takes into consideration operational impacts on the waste-to-energy facility; the addition of Thermal DeNOx for the reduction of NOx emissions will add costs of between $2 and $5 per ton of total waste processed by the facility, which includes 750 TPD of municipal solid waste in addition to the sludge.

analysis of alternative methods of sludge treatment and disposal in the northeastern U.S. indicated that costs for sludge treatment and disposal range from $331 to $441 per dry-tonne ($300 to $441 per dry-ton). Thus, based on the conservative budgetary capital and operating costs estimated above, the proposed co-incineration of sludge in existing waste-to-energy facilities warrants further examination, as the costs appear competitive on a per-dry-ton basis with alternative sludge treatment and disposal approaches.

SECTION 6

SUMMARY OF EVALUATION

CONCLUSIONS AND RECOMMENDATIONS

A number of conclusions can be drawn as a result of the MITE evaluation of the Pilot Test Program. All tests performed in the Pilot Test Program were performed in accordance with the agreed-upon protocol, except as noted in Section 3, page 10.

- The limited Pilot Test Program indicates that sludge was co-incinerated with solid waste up to a maximum ratio of 11.3 percent dry sludge per pound of MSW with the injection of 3.5 to 5.5 kilograms (pounds) of oxygen per kilogram (pound) of sludge, while maintaining relatively constant MSW-feed rates.

- Based on conservative budgetary capital and operating cost estimates, oxygen-enriched co-incineration of municipal sewage sludge in existing waste-to-energy facilities appears competitive, on a per-dry-ton basis, with alternative sludge treatment and disposal approaches and therefore warrants further examination.

- Modifying an existing waste-to-energy facility to incorporate oxygen-enriched co-incineration would likely require a permit amendment, including an attendent review and approval process. As such, specific permit amendment requirements, costs, and length of the approval process should be ascertained prior to implementation.

Technical issues requiring further evaluation prior to commercial application of APCI's oxygen-enriched co-incineration technology include:

- confirmation of the long-term reliability of the proprietary sludge system;

- determination of the long-term impacts of the introduction of sludge, oxygen, and moisture into existing waste-to-energy units relative to fouling, corrosion, performance, availability, and air pollution control equipment, including the potential need to add additional control technology or modify existing controls; and

- determination of the effect that introduction of high moisture sludge and oxygen into the combustion environment will have on organic pollution emissions, and confirmation of expected oxygen consumption per dry ton of sludge to a range consistent with the need to properly size and economically evaluate the oxygen production requirements.