THE ENVIRONMENTAL CHARACTERIZATION OF RDF COMBUSTION TECHNOLOGY

Mid-Connecticut Facility
Hartford, Connecticut

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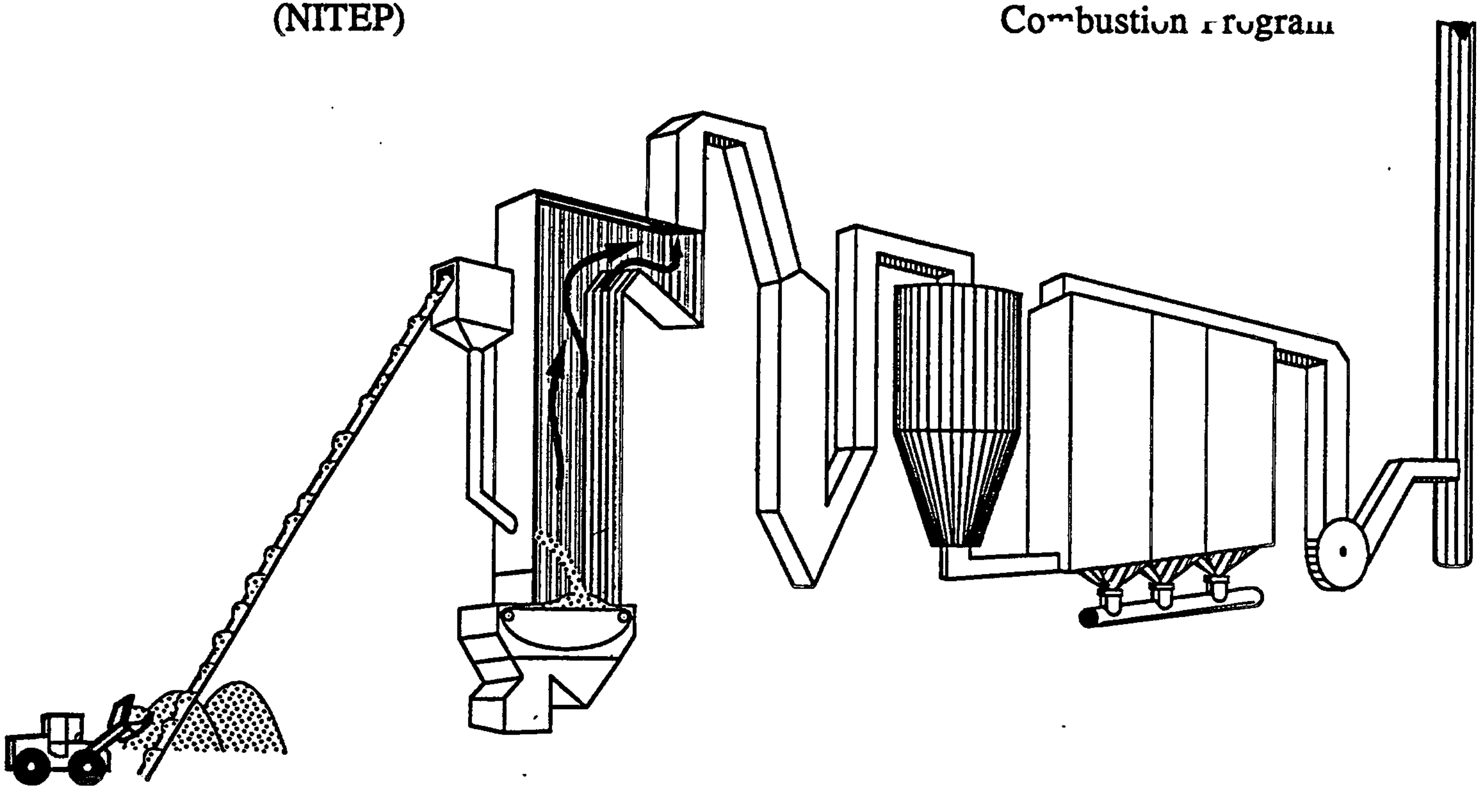
Environment Canada
National Incinerator Testing
and Evaluation Program
(NITEP)

United States
Environmental Protection Agency
Municipal Waste
Combustion Program



Volume I

Summary Report

June 1992

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Solid Waste Management Division
Office of Waste Management
Conservation and Protection
Environment Canada
Ottawa, Ontario
K1A 0H3

Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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ABSTRACT

The environmental characterization of refuse-derived fuel (RDF) semi-suspension burning technology was undertaken jointly by Environment Canada and the U.S. Environmental Protection Agency as part of ongoing programs of both agencies which assess municipal solid waste combustion technologies. The main objective of this program is to define optimum design and operating conditions to minimize emissions of concern. The facility tested is located in Hartford, Connecticut, and represents a "state-of-the-art" technology, including a spray dryer/fabric filter air pollution control (APC) system for each unit.

The selected RDF combustion system was tested extensively in 1989 over a two-month period. Based on 28 characterization tests, a series of 13 performance tests (PT) was successfully completed. The 13 PT runs provide results at 4 different steam production rates, for a variety of combustion conditions deliberately set to range from good to very poor. The PT runs were grouped into 7 discrete test conditions for the combustion system and 9 test conditions for the APC system. Operating conditions for the APC system included 3 different flue gas temperatures and a range of acid gas removal efficiencies deliberately varied from low to high.

All incoming wastes and each ash residue stream were weighed, sampled and analyzed. Key incinerator and APC system operating variables, such as refuse feed rate, temperatures, undergrate/overfire air distribution and other process parameters, were monitored by an extensive computer network system on a "real time" basis. A wide range of analyses was carried out on gas emissions and all the ash discharges, including analyses for polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzo furans (PCDF), polychlorinated biphenyls (PCB), chlorophenols (CP), chlorobenzenes (CB), polycyclic aromatic hydrocarbons (PAH), over 30 heavy metals, and acid gases.

Some of the key conclusions of the test program are as follows:

- Very low concentrations of trace organics, heavy metals, and acid gases in stack emissions were observed under all tested operating conditions. For example, total PCDD/PCDF emissions were less than 1.5 ng/Sm^3 in all tests.

- High removal efficiencies by the APC system were attained for trace organics in the flue gas during all tests. For example, PCDD and PCDF removal efficiencies exceeded 99%.

- Removal efficiencies by the APC system typically exceeded 98% for all metals in the flue gas, except mercury, for which the removal efficiencies ranged from 96% to 99%.

- RDF spreader stoker combustors can be operated with low carbon monoxide (CO) concentrations under steady state conditions. Average CO concentrations below 100 ppm were attained in a number of the completed 5 to 6 hour tests.

- Based on an input/output comparison, the estimated average net destruction efficiencies for trace organic compounds were 96% for good combustion conditions and 90% for poor combustion conditions.

- Concentrations of PCDD/PCDF in the bottom ash and grate siftings were at or below the detection limit. Over 99% of the total PCDD/PCDF associated with the residues was measured in the fabric filter ash.

- Trace organic contaminants in the ashes, including PCDD, PCDF, CB, and PAH, were not soluble in water.

- Only very small amounts (typically less than 10%) of most trace metals present in the ashes were soluble in water.

- Results from different leach tests indicate that a significant reduction in metal mobility was achieved through both physical encapsulation and chemical fixation for fabric filter ash that was solidified using cement and waste pozzolanic materials.

- Significant multi-variate correlations were found between a number of trace organics (e.g., dioxins) at the furnace exit (i.e. before APC system) and operating variables that are good indicators of combustion conditions, such as combustion air distribution. These variables were identified as potential parameters which could be used to control incinerator operating conditions to ensure minimal trace organics in the flue gas entering the APC system.

- Significant multi-variate correlations were identified between trace organic emissions from the furnace and easily monitored variables such as carbon monoxide, total hydrocarbons, nitrogen oxides, flue gas moisture, and furnace temperature. These variables could be employed as early warning signals of high trace organic emissions to the APC system.

- The removal of acid gases and trace organic compounds by the APC system correlated best with increased sorbent-to-acid-gas ratio (stoichiometric ratio) and decreasing spray dryer outlet temperature.

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ACKNOWLEDGEMENTS

We would like to thank everyone involved in the Mid-Connecticut refuse-derived fuel incinerator emissions testing program. The program was cofunded by Environment Canada, Energy Mines and Resources Canada, and the U.S. EPA; and was undertaken by Alliance Technologies Corporation. In addition, California Air Resources Board funded the particle sizing and hexavalent chromium portions of the program, and contributed to other ash and gas sample analyses. In particular, we are grateful to Mr. G.A. Gross from the Connecticut Resources Recovery Authority, Mssrs. R.M. Hartman and G. Boley from Combustion Engineering (now ABB Resource Recovery Systems), and the plant operators for their cooperation and assistance. Over 40 engineers, chemists and technicians were involved on-site while many dozens more provided laboratory support; without whose efforts and dedication this test program would not have been a success.

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Mr. Abe Finkelstein	Dr. Theodore Brna	Mr. Edward Peduto
Scientific Authority	AEERL	Program Manager
Environment Canada	U.S. EPA	Alliance Technologies Corp.

1 INTRODUCTION

1.1 PROGRAM BACKGROUND

The incineration of municipal solid waste (MSW) offers not only a practical waste management option, but also a means for energy recovery. However, emissions from MSW incinerators and their environmental impacts have become issues of major concern in both the United States and Canada. The release of previously undetected metals and trace organics from poorly designed, controlled, and/or operated incinerators has caused negative public perception of MSW incineration.

Recognizing these concerns, regulatory agencies in Canada and the United States have undertaken comprehensive programs to gather and analyze data on MSW combustion.

As part of its evaluation of incinerator technology, Environment Canada (EC) initiated the National Incinerator Testing and Evaluation Program (NITEP). This program provides data for determining how incinerator design, combustion characteristics, methods of operation and air pollution control systems affect the release of pollutants to the environment. Using criteria established in Phase 1 of NITEP, EC has examined incinerators representing 3 generic designs:

	Incinerator Design	**Location**	**Date of Release of Summary Report**
1.	Two-stage combustion (modular technology)	Parkdale P.E.I.	1985
2.	Waterwall moving grate mass burning system	Quebec City Quebec	1988
3.	Refuse-derived fuel (RDF) semi-suspension burning system	Hartford Connecticut	1992

These designs, along with fluidized bed combustion and others, encompass projected future trends in incineration technology.

The United States Environmental Protection Agency (EPA), through the Municipal Waste Combustion Program, has conducted characterization and compliance tests on a number of incinerators (e.g. Marion County, OR; Biddeford, ME; and Millbury, MA; Hartford, CT; and Montgomery County, OH). This information has been used in the revision of air quality regulations for new sources and guidelines for existing sources. This information has also been applied to the identification of the mechanisms by which pollutants, such as trace organics and heavy metals, are produced in, destroyed in, or removed from waste combustion systems and flue gas cleaning systems.

This summary report addresses the activity related to an extensive test program carried out at the Mid-Connecticut Hartford Project in Hartford, CT., under the joint direction of Environment Canada and US EPA. Alliance Technologies Corporation of Lowell, MA. conducted the tests under contract.

1.2 PROGRAM OBJECTIVES

The overall objectives of this joint EC/EPA project were:

Environment Canada -

- Define optimal design and operating characteristics.
- Relate operating conditions to emissions.
- Identify best practical control options.
- Investigate design and operating guidelines for future applications.
- Incorporate accepted dioxin/furan sampling and analysis protocols.
- Investigate dioxin surrogates.
- Facilitate construction of new incinerators.

U.S. EPA -

- Establish baseline emissions from a RDF-fired combustion source.
- Compare performance and emissions from the various types of municipal waste combustion systems.
- Evaluate design and operating parameters.
- Evaluate add-on pollution control devices.
- Establish design and operating criteria for combustion and flue gas cleaning systems.

Pollutants considered in this program included chlorinated tetra- through octa-dioxin/furans (PCDD/PCDF), chlorobenzenes (CB), chlorophenols (CP), polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH), metals, acid gases, combustion gases, and particulate matter. Some of these pollutants may not be regulated, but they have been examined for their prevalence in emissions from MSW incinerators so that regulations/guidelines may be developed based on effective control.

1.3 RDF TEST SITE

This project was conducted on Unit No.11 at the Connecticut Resources Recovery Authority's (CRRA) Mid-Connecticut Resources Recovery facility in Hartford, Connecticut. The RDF unit was designed and is operated by ABB Resource Recovery Systems (ABB/RRS). The unit is designed to handle a full steam load of 105,000 kg/h (231,000 lb/hour). Emissions are controlled with a lime spray dryer absorber followed by a fabric filter system. Chapter 2 describes the facility in further detail. Unit No. 11 was specifically selected for use in this project because of its availability and the presence of additional process monitoring equipment.

1.4 PROJECT REPORTS

The data and conclusions generated by the Mid-Connecticut RDF incinerator test program are presented in six volumes:

Volume I - Summary Report, describes the most significant results of the test program.

Volume II - Test Program and Results, provides an in-depth discussion of the results and rationale for the various tests conducted at the site. Detailed data analyses and the conclusions drawn from these tests are also provided.

Volume III - Sampling and Analytical Procedures, provides the details of the sampling and analytical methodologies used for the testing program. This volume discusses any modifications made to standard reference procedures to overcome any inherent limitations or difficulties encountered during the program.

Volume IV - Project Data, contains all detailed data as well as summary sheets and graphical representations. This volume provides further back-up to the data and conclusions contained in Volume II. In addition, the data are organized into different formats to facilitate comparison and interpretation of results. Volume IV contains three books presenting: reduced data (Book 1), raw data (Book 2), and single and multiple regression analyses (Book 3).

Volume V - Ash/Residue Characterization and Solidification, provides the results of the leachate program for both organic and inorganic contaminants conducted by Environment Canada's Wastewater Technology Centre.

Volume VI - External QA/QC Evaluation Report, contains the details of the independent external quality assurance/quality control (QA/QC) program.

1.5 STRUCTURE OF THIS REPORT

Chapter 2 describes the RDF facility, while Chapter 3 provides a description of the program, including approach to testing, sampling locations, the characterization test series and the selection of process conditions for performance testing. Chapter 4 reviews sampling and analytical protocols and quality assurance/quality control procedures.

The results of the performance tests for the combustion system are outlined in Chapter 5, while the results of the performance tests for the air pollution control system are outlined in Chapter 6. In Chapter 7, key findings of ash characterization tests are provided. Conclusions and recommendations are summarized in Chapter 8.

2 FACILITY DESCRIPTION

2.1 SITE OVERVIEW

The facility selected for the joint EC/EPA test program was the Mid-Connecticut Resources Recovery Facility, owned by the Connecticut Resources Recovery Authority (CRRA). This facility was designed and constructed by ABB/RRS at Connecticut Light and Power's South Meadows generating station along the south side of the Connecticut River in Hartford, Connecticut. The RDF processing facilities were built on land adjacent to the existing generating station.

The Mid-Connecticut facility consists of:

- a waste processing facility;
- a steam generation power block;
- an electrical generation system.

The waste processing facility, operated by the Metropolitan District Commission (MDC), processes raw municipal waste into RDF, which is then provided to the steam generation power block. The power block facility is operated by ABB/RRS and includes three new ABB Combustion Engineering (CE) boilers, ash handling systems, and pollution control systems. The electricity generating portion of the facility is owned by Connecticut Light and Power. The facility commenced operation in 1987.

2.2 PROCESS DESCRIPTION

The facility is designed to process 1814 tonnes (2000 tons) per day of MSW received from 44 communities in the greater Hartford area. The facility design as shown in Figure 2-1 includes fuel preparation, steam generation, and combustion gas cleanup. The RDF preparation and storage areas are housed in a separate building located approximately 360 metres to the south of the boiler house. The three RDF-fired spreader-stoker boilers are located inside the boiler house. Adjacent to the boiler house are the combustion air preheaters, forced draft fans, spray dryer absorbers, fabric filter modules, induced draft fans, and the exhaust gas outlet stack (Figure 2-2).

2.2.1 RDF Preparation/Handling System

As shown in Figure 2-1, conversion of MSW into RDF consists of the following steps:

1. Reception of the raw MSW at the refuse truck unloading area.
2. Manual inspection and picking process to remove:
    - large bulky items
    - smaller noncombustible items
    - potentially explosive items such as propane tanks.
3. Flailing and primary shredding for cutting open bags and waste size reduction
4. Magnetic separation for removal of ferrous materials
5. Trommel screening for dirt, glass, and fines, and secondary shredding to obtain the proper RDF size

1. Refuse Truck Unloading Area
2. Refuse Shredders
3. Ferrous Metal Magnets
4 Primary Separation Units
5. Secondary Shredders
6. Metal Outloading
7. Residue Outloading
8. Secondary Separation
9. Refuse Derived Fuel (RDF) Storage
10. Refuse Derived Fuel (RDF) Conveyors
11. Barge Delivery of Coal
12. Coal Storage
13. Coal Reclaim Conveyors
14. RDF & Coal Conveyors to Boilers
15. C-E VU-40 RDF and/or Coal Fired Boilers
16. High Efficiency Emission Control Equipment (Dry Scrubber/Baghours)
17. Stack
18. Turbine Generators
19. Switch Yard

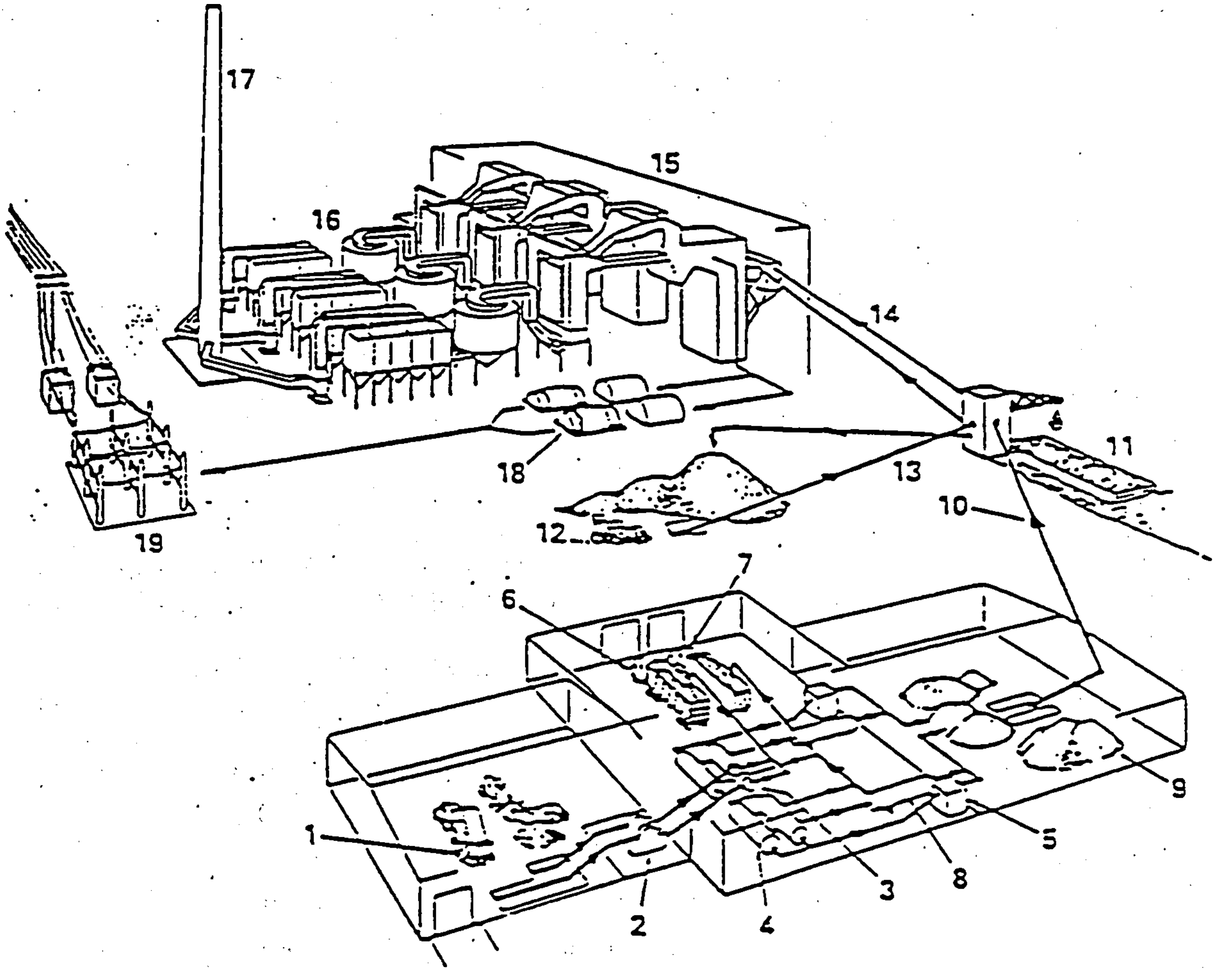


Figure 2-1. Mid-Connecticut Facility Design

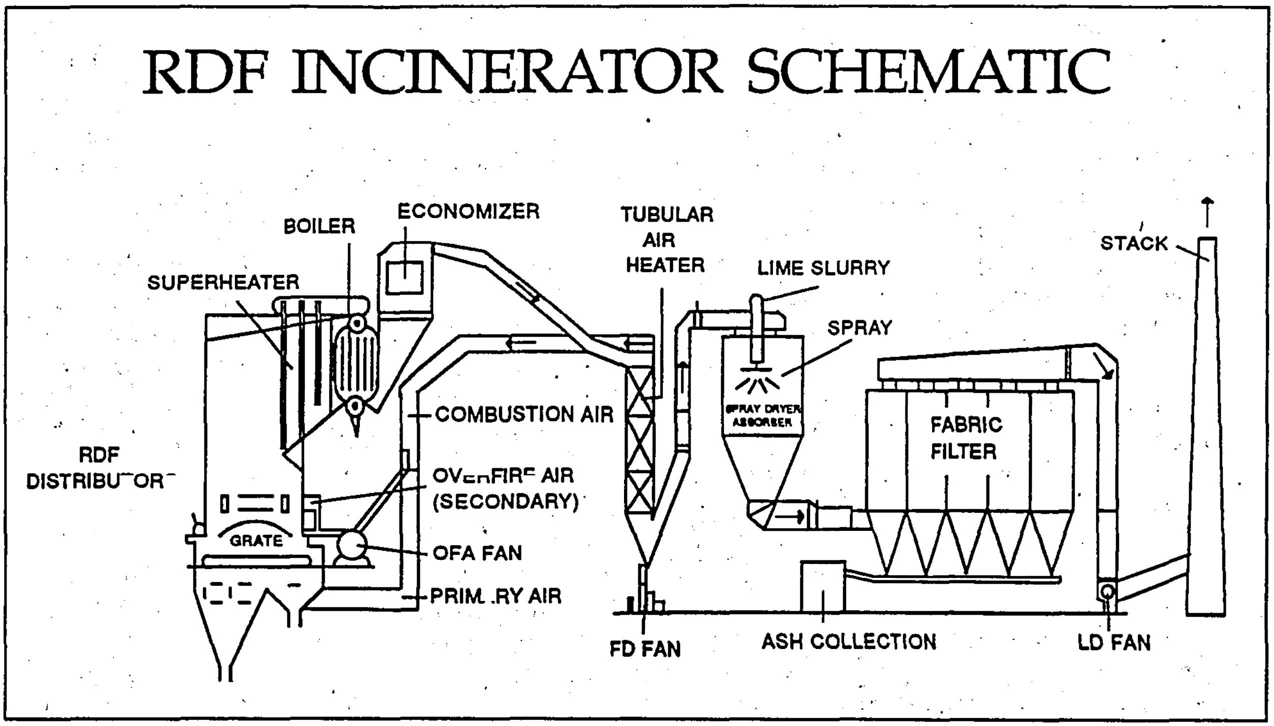


Figure 2-2. RDF Incinerator Schematic

The processed RDF is then conveyed to the storage area where it awaits transfer to the boiler house for burning.

The processing facility has two parallel processing lines to provide high throughput of RDF as well as providing a backup system during scheduled maintenance and downtime. The processing capacity of one line is sufficient to maintain load on two of the three boilers. Two parallel conveyors leave the RDF storage area, pass through the RDF/coal midstation,and then enter the upper level of the boiler house. RDF may be fed from either conveyor to any of the three feed bins above the boilers. Within the bins are screw auger feeders which break up clumps of RDF and meter the downward flow of the RDF to the boiler.

2.2.2 Steam Generating System

The Mid-Connecticut facility operates three identical RDF spreader-stoker steam generators, referred to as Units 11, 12, and 13. Unit 11 was selected for this test program. Each VU-40 steam generator is designed for a maximum continuous rating (MCR) of 29.1 kg/s (231,000 lb/hr) at 6.1 MPa-gauge (880 psig) and 441°C (825°F) when firing RDF.

The fuel burning system includes ABB's Refuse Combustor stoker which has been specifically designed for resource recovery facilities burning RDF alone, or in combination with coal. Four pneumatic distributors spread the RDF across the width of the combustion grate. The grate includes a self-cleaning key design to remove fused/clinkered ash during grate operation. Ten undergrate air zones (two rows of five each, parallel to the direction of grate travel) allow the operator to optimize the combustion process on the grate and to respond quickly to "piling" situations by manual adjustment of undergrate air (UGA) zone dampers.

Coal is a secondary fuel and is used as required to maintain steam demand from the boilers. Coal was not fired in Unit 11 during the testing program.

Each boiler is equipped with a forced draft centrifugal fan to supply the required combustion air. There are separate overfire air (OFA) systems for RDF and coal. The OFA system for RDF is equipped with four tangential overfire air windbox assemblies located in the furnace corners. At each corner windbox assembly, there are three OFA levels which are separately controlled. Preheated combustion air enters the furnace tangentially to form a vortex. The resulting internal recirculation and turbulence in the bulk gas provide longer furnace residence times for burning low density RDF particles entrained by the gas stream. The normal OFA/UGA distribution percentage is 30/70, but the OFA capacity can be raised to 50 percent.

The flue gases generated in the combustion chamber flow through a superheater, which is a vertical two-stage design with parallel steam and gas flow. Upon leaving the superheater, the combustion gases pass through a 28-tube deep steam generating bank which includes a vertical outlet duct to the economizer. The economizer consists of two horizontal banks of in-line tubes. Subsequently, the flue gas goes to a combustion air preheater.

Each steam generator is equipped with one 3-pass horizontal tubular air preheater. Flue gas flows over the tubes and the combustion air flows through the tubes. A steam coil air preheater maintains the average cold end temperature high enough to prevent sulfuric acid corrosion of the air heater. After the air preheater, the flue gas flows through the air pollution control system and then, via an induced draft (ID) fan, to the stack.

Each boiler is equipped with soot blowers located between superheater banks, at the boiler bank inlet, in the boiler bank centre cavity, in the economizer and in the air preheater. Ash deposits are released during the soot blowing cycles and are collected in hoppers under the economizer and air heater.

The ash removal system for each boiler consists of two streams. The first stream collects the bottom ash, economizer ash, and stoker siftings. A submerged scraper conveyor is used for bottom ash collection. Mechanical flight conveyors are used to transport the ash streams. The second stream collects the baghouse and air heater ash. The two streams are combined after the baghouse ash and air heater ash have been conditioned in pug mills. The combined ash stream is then transported to storage for eventual disposal.

2.2.3 Air Pollution Control System

Each boiler has a dedicated two-stage flue gas cleaning system composed of a spray dryer absorber vessel for the neutralization of acid gases, followed by a reverse-air-cleaned fabric filter for the removal of particulate (fly ash, reaction products and unused $Ca(OH)_2$) and gaseous pollutants. The cleaned gas stream passes through the system's ID fan and enters the outlet breeching for discharge through the common outlet stack. Major subsystems to the above individual gas cleaning systems include a common lime receiving/storage and lime slurry preparation/distribution system.

The spray dryer absorber vessel removes acid gases from the boiler flue gas and produces a dry product for disposal. This is accomplished by introducing a very fine spray of absorbent slurry into the flue gas stream and providing intimate contact and sufficient time for the sorption and drying process to occur. The spray dryer absorber design consists of the following major components: inlet flue gas distributor, rotary atomizer spray machine, spray dryer absorber vessel, and flue gas outlet.

Concentrated slaked lime slurry is delivered on process demand to the individual additive feed tanks. There, the slurry is further diluted with water to the correct concentration required of the process parameters (i.e. to achieve the required spray down temperature and acid gas removal requirements). The slurry is then pumped from these individual additive feed tanks to their corresponding atomizers to be finely atomized within the spray dryer absorber vessel. Note that pond water is the primary dilution water for slaked lime when it is available. River water is used when pond water is not available.

The flue gas enters the top of the spray dryer absorber vessel through the distributor which consists of a primary and secondary swirl chamber. The primary and secondary swirl chambers distribute the flue gas through annular openings surrounding the atomizer wheel. The secondary gas passage can be set from 100 percent capacity to near shut-off, which provides operational flexibility for boiler conditions from 100 percent maximum continuous rating to 40 percent, without sacrificing performance. The spray dryer absorber vessel is sized to provide the contact between the flue gas and sorbent necessary to complete the acid gas sorption reactions and ensure product dryness.

Adiabatically cooled and treated flue gas flows from the spray dryer absorber vessel to the outlet duct. All of the dried product and ash are entrained in the flue gas as it travels from the vessel to the fabric filter particulate removal. This bottom discharge design eliminates the requirements for absorber solids removal equipment and avoids solids plugging.

Each fabric filter consists of 12 modular reverse air compartments arranged in two rows of six compartments. The inlet/outlet manifolds are located between the two rows. Each compartment contains 168 woven glass fiber filter bags arranged in 12 rows of 14 bags. The modular compartments have a three-bag reach from the walkway area. The bags are automatically cleaned using either a differential pressure signal or a timed signal to initiate the cleaning cycle. The compartments are cleaned sequentially, one at a time, with the other compartments remaining on-line. A bag collapsing action, plus reverse air flow, dislodges the dust from the inside of the bags permitting it to fall into the hoppers below.

Each fabric filter system is equipped with a bypass to route process gas directly to the stack without passing through the fabric filter. This is necessary in start-up and emergency conditions where high temperatures, low temperatures, or high differential pressure may be encountered. The bypass system is activated either automatically or manually.

3 PROGRAM DESCRIPTION

3.1 APPROACH TO TESTING

The test program conducted at the Mid-Connecticut Resource Recovery Facility was designed to address the EC and EPA objectives described in Section 1.2, the major ones being:

- to establish baseline emissions from a RDF-fired combustion source
- to establish correlations between process operation and emission characteristics
- to define optimal design and operating characteristics

The testing was divided into 2 phases. The characterization tests (CT) provided process data that were used to define the key operating variables to be investigated in detail during the subsequent performance tests (PT). This first phase also provided the opportunity to verify test procedures to be used during the performance test phase. The PT phase was designed to provide data to be used to establish correlations between process operation and emission characteristics.

3.2 SITE SELECTION

The criteria used by EC and EPA for the selection of the Mid-Connecticut facility were:

1. RDF to be used as the sole fuel during the test program;
2. Facility to be representative of modern design, including RDF preparation and feed systems, boiler and combustion systems, and air pollution control devices (APC);
3. Operational flexibility incorporating technical capabilities, management cooperation, permit considerations, and site logistics regarding installation of monitoring equipment;
4. Access to sampling locations throughout the steam generation and APC system.

Site preparation did not require any major modifications to be made to the feed system, Unit 11 combustion system or the APC system for this program. However, numerous modifications, as discussed below, were required at the sampling points to provide access to the process streams.

3.3 SAMPLING LOCATIONS SELECTION AND PREPARATION

The feed and ash streams were measured or sampled at 10 locations; 8 of which required modifications. The flue gas stream had 5 sampling locations. These are shown in Figure 3-1.

The following subsections briefly describe the locations that were used and the modifications made.

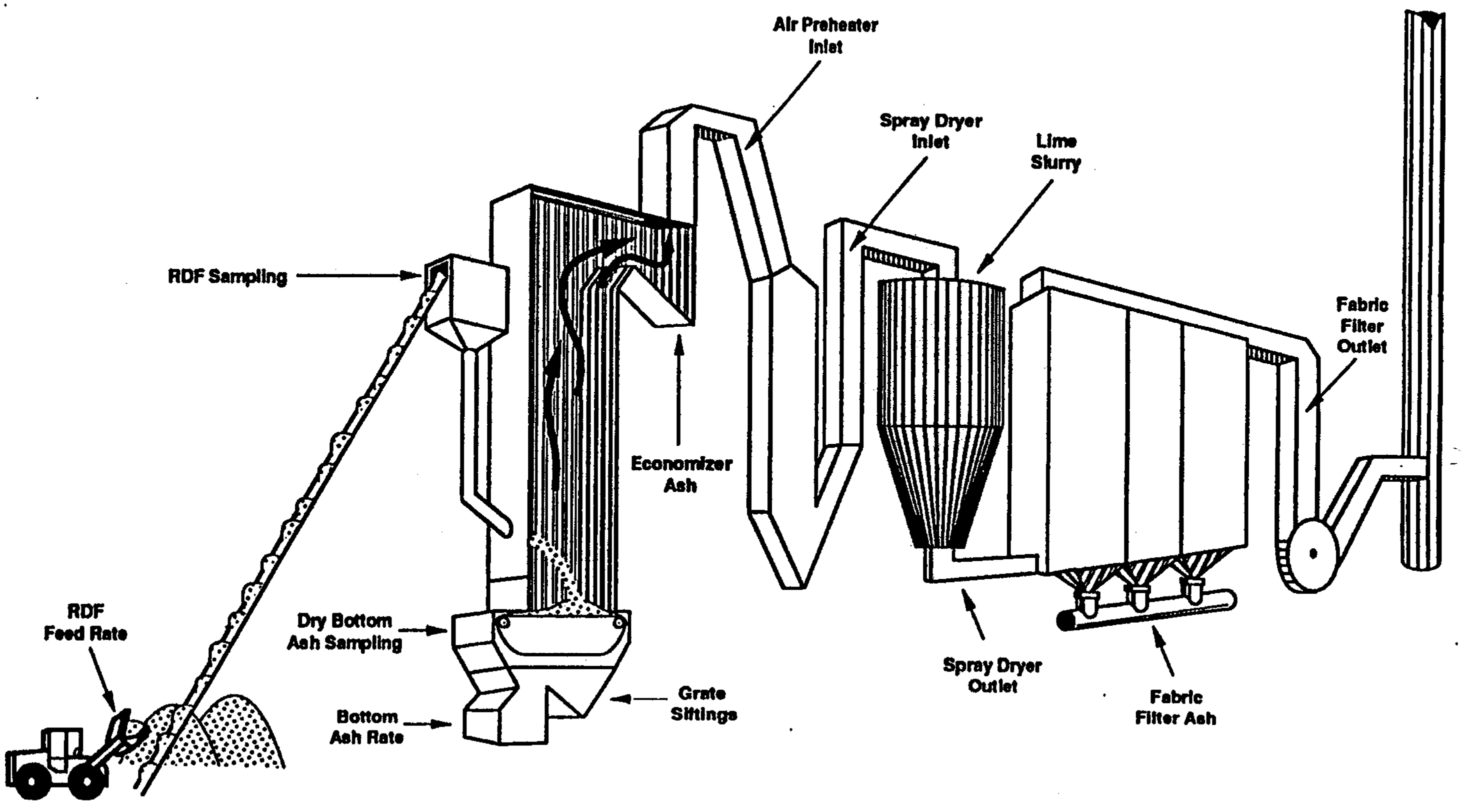


Figure 3-1. Process Schematic Showing Sampling Locations

3.3.1 Feed Streams

At the RDF preparation area, each load of RDF was weighed as it was placed onto the dedicated conveyor by the front-end loader. The data were used in determining the mass feed rate and energy input to the system.

In order to characterize the quality of the feed to the system, the RDF was sampled at the RDF midstation, located approximately halfway between the preparation facility and the boiler house. The conveyor housing was modified with a hinged plywood door to provide access. A 1.3 cubic meter box was installed adjacent to the conveyor for receiving the composite RDF samples.

The makeup water for the lime slurry was supplied from the coal pond located adjacent to the coal pile. Samples were taken from a hose connected to the pond water supply line just prior to the entrance to the final slurry mixing tank.

The sampling valve was located in the penthouse of the spray dryer of Unit 11. This location was selected because of its accessibility, low slurry pressures, and its close proximity to the atomizer head itself. The latter factor was especially important due to slight dilution of the slurry upstream of this location with a water bleed line used for cooling purposes. Consequently, the slurry sampled was "as atomized". The only modification required was the installation of a reducing coupling to which a flexible Teflon sampling line was attached.

3.3.2 Ash Streams

Total collection was used to quantify the ash production rate of each ash stream for grate siftings, economizer ash and air heater ash. Each location was selected and modified accordingly to allow for the collection of a separate, discrete ash stream over the course of each test run. Under normal operation, the economizer ash and grate siftings are combined within a drag chain conveyor beneath the boiler before entering the quench tank. A large valve was installed in the economizer ash down-pipe several floors above the bottom level. A temporary stainless steel down-pipe was attached to the valve and the other end of this down-pipe was on the bottom floor, facilitating collection of the ash in empty steel drums.

Since the economizer ash was collected separately, only the grate siftings (GS) were serviced by the drag chain conveyor. To collect the entire GS stream before quenching, the bottom of the inclined drag chain conveyor was modified just prior to entering the quench tank by adding a collection hopper and downtube. A stainless steel hose connected the downtube to the collection drum.

The air heater hopper was unintentionally plugged during the tests and could never be cleared out sufficiently to collect any ash sample.

The analytical characterization of the bottom ash samples had to be done on a dry sample prior to quenching. This was accomplished by sampling the ash from the view ports at the front of the boiler from the ash bed itself. No modifications were required at this sampling point.

Because the bottom ash dropped directly off the front of the travelling grate into the boiler hoppers and then into the quench tank, the production rate of unquenched ash could not be measured directly. Therefore, the quenched bottom ash was diverted from the common collector conveyor shared by all three boiler units into a tare-weighed hopper. Samples were collected from each hopper and analyzed for moisture. The net dry weight of the bottom ash was determined by correcting for moisture.

A dedicated conveyor collected the fabric filter ash as it came off the two parallel West-East conveyors underneath the two banks of ash hoppers. The inclined pugmill conveyor was purposely shut off to allow the ash to accumulate at its base while the North-South conveyor was kept in service. As the ash was deposited, it was collected by a 15-cubic meter vacuum truck and weighed to yield the net ash production rate.

3.3.3 Flue Gas Streams

To verify the flow rate of preheated air to the boiler, 2 ports were installed in the twin horizontal ducts which provide preheated combustion air to the OFA nozzles, undergrate air, and other combustion air systems.

The **preheater inlet (PHI)** combustion gas was sampled in the inclined duct leading from the boiler to the combustion air preheater. Sampling point modifications consisted of the installation of 5 ports on the preheater inlet duct and the erection of a sampling platform and shelter. The installed ports were oriented on a vertical axis and were not perpendicular to the gas flow. This was a deviation from the standard method for siting isokinetic sampling ports, but was selected to facilitate sampling at this location.

The **spray dryer inlet (SDI)** was sampled to obtain measurement of a variety of organic and inorganic compounds before they came into contact with any control device. As this was an existing sampling location, only two modifications were required. Two ports were installed to allow the installation of the continuous emission monitoring (CEM) equipment. In addition, the platform was enlarged and safety nets were added.

The **spray dryer outlet (SDO)** was an intermediate sample point to provide scrubber outlet measurements of several gaseous pollutants, including acid gas concentrations in the APC system. This point was an existing sampling location with ports suitable for CEM equipment. The only modification required was the enlargement of the platform.

The **fabric filter outlet (FFO)** provided for measurement of a large variety of organic and inorganic compounds prior to their discharge from the stack. Removal efficiency data across the APC was determined for particulate matter, organic compounds, trace metals, and acid gases.

The FFO is a vertical rectangular duct with five ports arranged horizontally across the face of the duct. However, a diagonal support beam prevented access to the centre port for isokinetic sampling. Consequently, the trace organics, metals, and hexavelant chromium trains were traversed through the remaining four ports. The single point particle sizing train was run in the centre port. The volatile organic sampling train (VOST) was run in a centrally located port in the back of the duct, on a slightly higher plane upstream of the isokinetic trains. CEM probes were installed in adjacent ports in the back of the duct.

All process data, continuous gas data, pressures and temperatures were monitored throughout the tests via a data acquisition system. Relevant process data were gathered, recorded and displayed on a real-time basis. The system is further described in Chapter 4.

3.4 CHARACTERIZATION TEST SERIES

3.4.1 Objectives

The major objectives of the characterization tests (CT) were:

1. To familiarize test crews with the operation of the RDF incinerator;
2. To identify furnace/boiler/APC operating conditions which would be most appropriate for the performance tests; and
3. To verify sampling and analytical procedures to be used in the performance tests

3.4.2 Overview

The CT phase examined incinerator and APC system performance under steady state conditions as operating parameters were changed one at a time. The set of 28 operating conditions encompassed both normal and potential upset conditions. The tests were conducted during the period of January 11-25, 1989 and typically each lasted 1 or 2 hours.

The parameters that were monitored during the CT phase are summarized in Figure 3-2. Continuous emission monitoring at the inlet and outlet of the APC was the major analytical effort during the CT phase. Particulate testing, followed by loss on ignition (LOI) analysis, was conducted during half of the CT runs. During each test, relevant process data were monitored. In addition, familiarization runs involving an EPA modified Method 5 train for trace organics were conducted at the SDI and the FFO.

Ash, lime slurry, and RDF sampling were also conducted during the CT phase to identify potential complications in obtaining representative samples. These samples also provided a limited amount of analytical data and allowed verification of sample handling and preparation procedures. Perhaps the most important aspect of the stream sampling during the CT phase was to verify expected rates of ash generation.

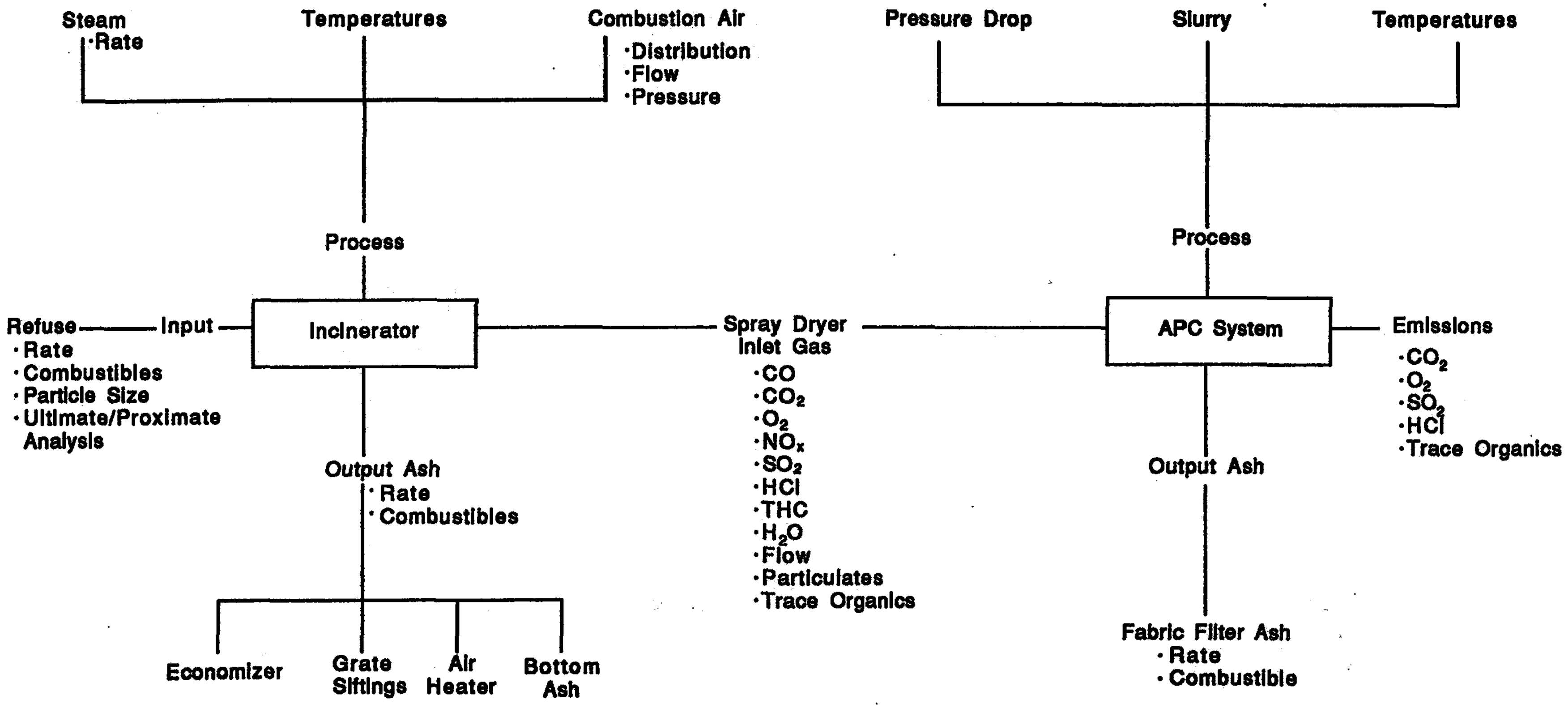


Figure 3-2 Characterization Test Sampling Parameters

3.4.3 Process Conditions of CT Program

The characterization test program investigated the following key operating parameters for the combustion process:

- refuse fuel input rate [steam production rate],
- air injection quantity and distribution [excess air level and distribution],
- combustion process temperature,

and for the air pollution control system:

- lime stoichiometry [lime slurry pressure and flow rate],
- gas temperature at the fabric filter outlet.

Five series of tests (Series A to E) which varied combustion parameters were completed as shown in Figure 3-3.

Four series of tests (Series K to N) which varied APC system parameters were also completed (as shown in Figure 3-4) and were integrated into the combustion test series. The APC test series examined the effect of stoichiometry at spray dryer outlet (SDO) temperatures of 105, 110, 140 and 177°C.

3.4.4 Summary of Characterization Test Results

Detailed results from the characterization tests are available in Volume II of the report series. Some relevant observations of results from the CT series are summarized below:

Stable Operation

In an effort to define stable operation, the variation in steam flow during each test period was evaluated and found to range typically from 2 to 8 percent.

An almost linear relationship was found between excess oxygen and steam flow. This relationship indicated that the combustion air flows could not be changed as easily as the boiler load.

Low Load Conditions

The low load conditions presented an operational problem for the boiler. This mode of operation provided lower CO emissions during the characterization test (but not the performance tests), but was the worst operating mode in terms of energy utilization. Therefore, it would not be economically practical to operate these units at low load conditions as a normal practice.

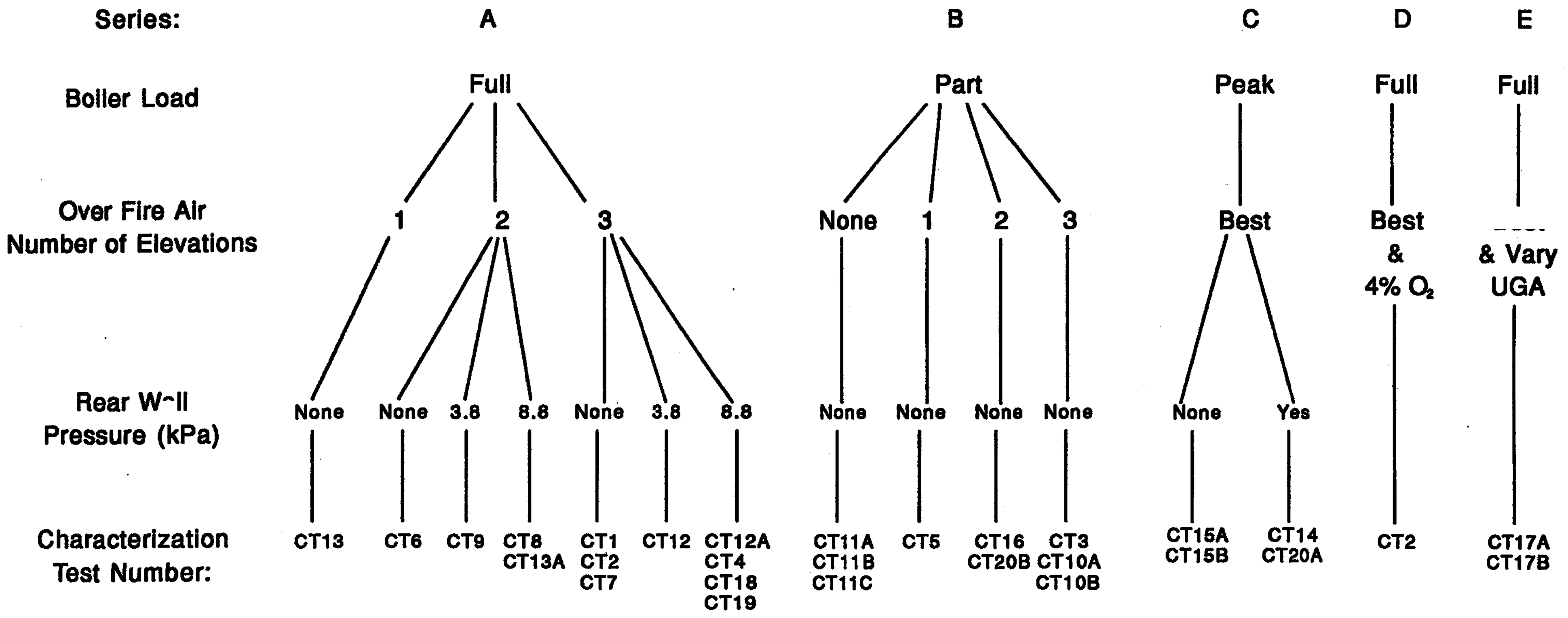


Figure 3-3 Characterization Test Operating Conditions For Combustion System Test Series

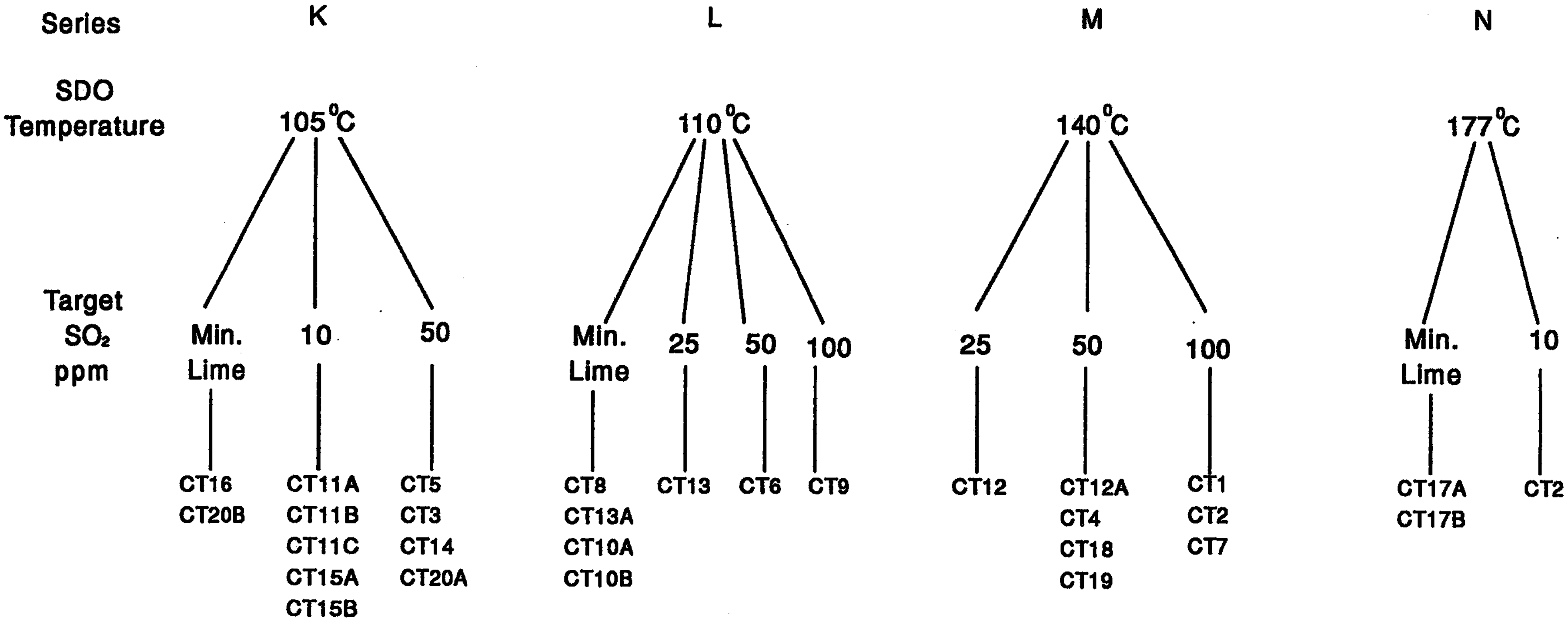


Figure 3-4 Characterization Test Operating Conditions For APC System Test Series

Peak Load Conditions

CO levels increased during most of the peak load tests due largely to the lack of fuel burnout before discharge from the grate. These conditions provide enormous amounts of heat on the grate, but also provide improper combustion conditions caused by the bed depth on the grate and improper mixing in the combustion zone.

Optimum Combustion

Optimum combustion operation appears to correspond to a steam production rate between 95,000 and 107,000 kg/h (210,000 and 235,000 lb/h). The most effective means of introducing combustion air was by rear wall over-fire air (RW-OFA), as this seems to provide the total mixing required to promote good combustion and to minimize CO production. Tangential OFA must also be used to mix the gases higher in the combustion chamber. Proper combustion air introduction and good combustion gas mixing corresponded with even fuel distribution and burning.

3.5 PERFORMANCE TEST SERIES

3.5.1 Objectives

To provide information on the environmental effects of RDF incinerator technology, the major objectives of the performance tests (PT) were:

1. To establish correlations between the operating parameters of an RDF incineration system and the resultant emissions;
2. To determine and investigate correlations between combustion parameters and flue gas compositions; and
3. To investigate formation of dioxin/furan precursors.

To meet these program objectives, a series of performance tests were designed to characterize in detail the feed and effluent streams while monitoring the associated operating parameters. Fourteen separate test runs were conducted between February 13 and March 1, 1989.

3.5.2 Process Conditions of PT Program

The targeted process conditions in the performance tests evolved from the results of the CT phase. Process parameters were chosen to provide test results at 4 different steam production rates, for a range of combustion conditions ranging from good to very poor. The quantity and distribution of combustion air to the furnace were also used in grouping the conditions. Operating conditions for the APC system included gas temperature in the spray dryer and SO_2 concentration after the fabric filter, which served as a surrogate indicator of lime stoichiometric ratio.

Figures 3-5 and 3-6 present the process conditions tested during the PT phase for the combustion system and for the APC system.

Thirteen of the 14 test runs attempted were deemed to be valid. Problems with the fabric filter ash collection truck invalidated one test run. The 13 valid runs were divided into 7 discrete test conditions for the combustion system and nine test conditions for the APC system. The APC system test conditions are actually a sub-set of the combustion system test conditions.

Ideally, triplicate testing would have been conducted at each combination of operating parameters. Triplicate testing would increase the statistical reliability of the data gathered for each test condition. However, cost and time considerations allowed only 15 test runs to be conducted. The test program was further shaped by the decision that it was more important to obtain as much valid data as possible at a variety of conditions as compared to conducting three runs at five conditions.

The performance test parameters sampled and monitored are summarized in Figure 3-7. Test results for the seven test conditions for the combustion system are described in detail in Chapter 5, while test results for the air pollution control system are presented in Chapter 6.

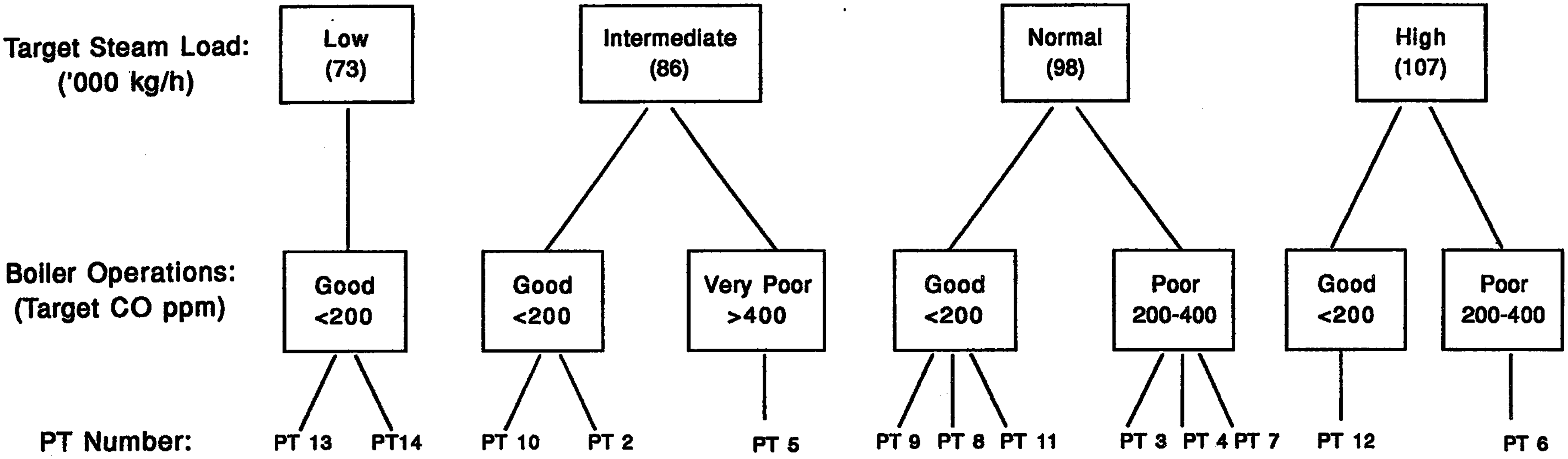


Figure 3-5 Performance Test Operating Conditions
For Combustion System Test Series

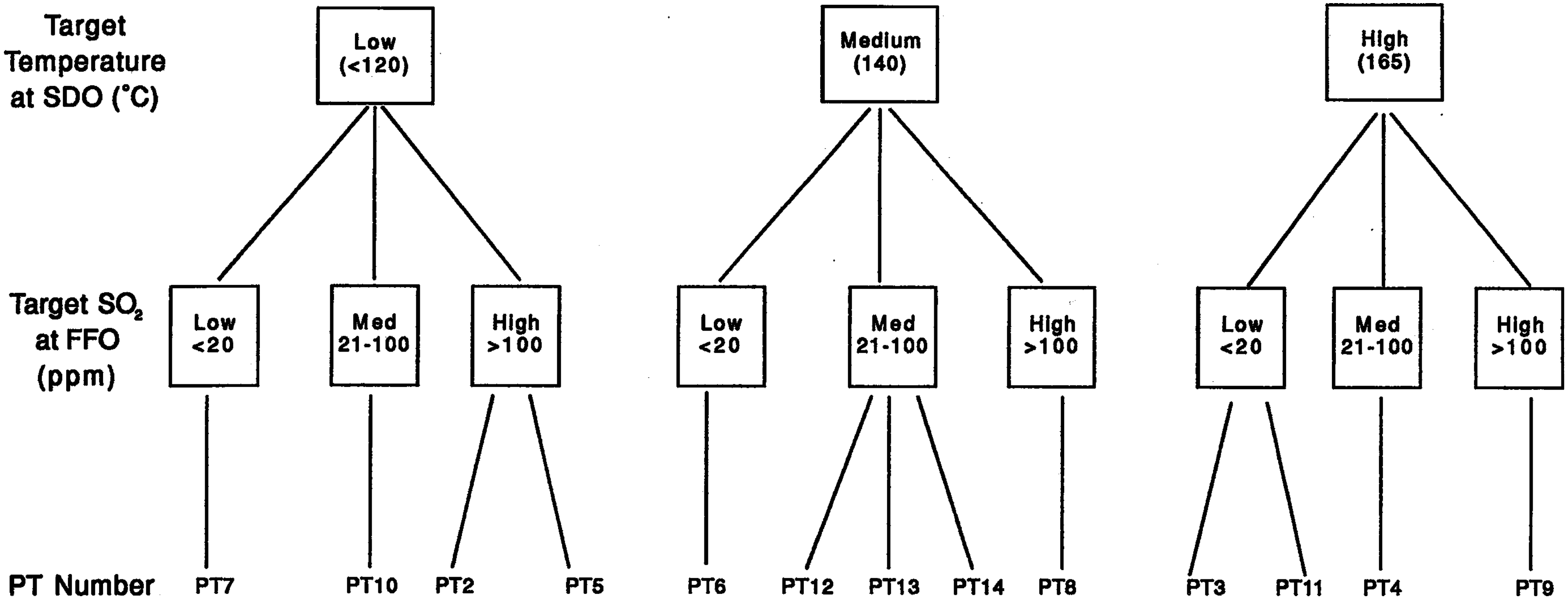


Figure 3-6 Performance Test Operating Conditions For APC System Test Series

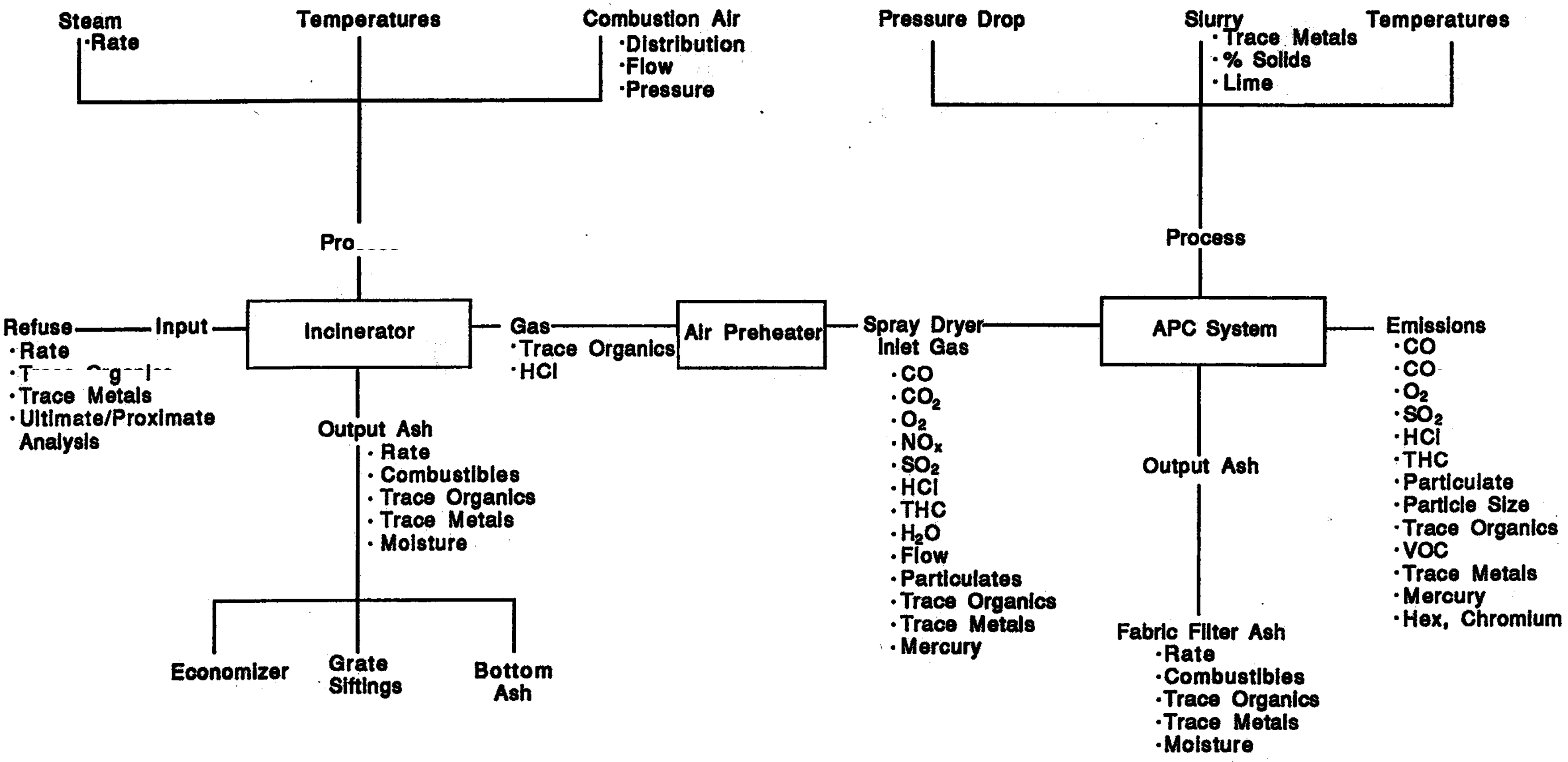


Figure 3-7 Performance Test Sampling Parameters

4 SAMPLING AND ANALYTICAL PROTOCOLS

4.1 OVERVIEW

The characterization of process conditions and emissions of the RDF-fired incinerator required a wide variety of measurements, using a variety of sampling and analytical protocols. These measurements were made at a number of diverse locations throughout the facility as shown in Figure 3-1 and as discussed in Chapter 3.

All sampling and analytical methodologies were based on recognized protocols. Modifications to existing methods were sometimes necessary to overcome certain sampling or analytical difficulties or to resolve differences in procedures normally used by EC and EPA.

This chapter briefly describes the sampling and analytical procedures used for process stream measurements, combustion gas sampling, and process monitoring. Additional information may be found in the quality assurance project plan (QAPP) prepared for this program described in Volume VI and in the sampling/analytical methods presented in Volume III.

4.2 PROCESS STREAM SAMPLING

The process streams were sampled at eight locations. Three of these were feed streams to the system (RDF feed to the boiler, and pond water and lime slurry feed to the spray dryer). The remaining five streams were ash discharges from various key locations within the combustion/pollution control system.

The **RDF feed rate** was determined at the RDF preparation area, by weighing each load of RDF as the front-end loader placed it onto the dedicated conveyor. A Tuffer weighing device was attached to the hydraulic lift system of the loader to provide this information. The times at which the loads of RDF were placed were also recorded.

RDF samples were taken at the point where RDF dropped off the conveyor to fall into the boiler feed bin. A 0.06 m^3 (2 ft^3) sample was scooped from the stream every 30 minutes. To account for residence times in the feed bin, sampling was begun 15 minutes before the start of a test run and ended approximately 15 minutes before the end of the run.

The collected RDF was emptied into the mixing box and was spread out over the surface to provide for fairly uniform layers. After coning and quartering the composite sample three or four times, the remainder was divided equally into three portions which were then double bagged, sealed, and placed in plastic pails with sealable lids.

The **pond water** that was used as makeup water in the slurry mixing tank was sampled three times during each test run to further characterize the lime slurry feed. The samples were collected from a flexible hose inside the slurry mixing room. The valve was opened and the hose purged prior to collecting each grab sample. The samples were combined in a single 500 mL amber glass jar.

The **lime slurry** was sampled three times during each 8-hour test period from a valve in the slurry supply line leading to the atomizer head of the spray dryer. A 150 mL slurry sample was drawn into the impinger by a meter box pump.

Grate siftings and economizer ash were collected in their entirety in tared drums through flexible downtubes. To determine ash production rates, the filling time and weight of each drum were recorded. After collection and weighing, a core sample of the ash was taken from the drum.

Dry bottom ash samples were collected at 30 minute intervals during each test run from the grate through the four rectangular viewing ports located at bed level in the front of the boiler. Due to the high temperature, a modified stainless steel pan-type scoop with a long handle and hinged lid was pushed into the ash bed through the viewing ports. The composite container contained dry ice to cool the sample and to quench any continuing combustion.

Quenched bottom ash samples were collected from a dumpster placed beneath the drop-off point of the dedicated bottom ash conveyor, using a trowel or scoop and then placed into a five-gallon polyethylene bucket.

When full, or at the end of the test run, the dumpster was weighed to determine the total wet bottom ash production rate. The moisture analysis yielded the weight of water from which the dry bottom ash production rate could be calculated.

Fabric filter ash (FFA) was collected at the base of the inclined conveyor leading from the drag chain conveyor to the pugmill. This inclined conveyor was shut off, allowing the FFA to settle and collect at its base. A vacuum truck continuously removed the FFA out of this area. At 30 minute intervals, the vacuum truck was shut down to allow enough FFA to accumulate to provide grab samples. When full or at the end of each run, the tared truck was weighed to obtain the ash production rate.

4.3 FLUE GAS SAMPLING

Flue gas sampling and monitoring were conducted at four locations downstream of the combustion system:

- air preheater inlet [API],
- spray dryer inlet [SDI],
- spray dryer outlet [SDO],
- fabric filter outlet [FFO].

Parameters examined included bulk gas composition, particulate matter, particle sizing, hydrogen chloride, trace organics, trace metals, mercury, and hexavalent chromium.

Continuous Emission Monitoring was completed at the SDI, SDO and FFO locations using the instrumentation and parameters listed in Table 4-1. The signals from the instruments were tied into the data acquisition system to provide real-time output.

Table 4-1. CEM Locations/Parameters/Instruments

CEM Location	Responsibility	Parameter	Instrument	Principle
Spray Dryer Absorber Inlet (SDI)	Environment Canada	O_2	Beckman 755 Teledyne 320-P-4 Teledyne 3208B-RC	Paramagnetic Electrochemical Electrochemical
		CO_2	Beckman 865 Anarad AR-421	NDIR NDIR
		CO	Bendix 8501-5BA Bendix 8501-5CA	NDIR NDIR
		SO_2	Western Research 721A Western Research 721A	NDUV NDUV
		NO_x	TECO 10AR TECO 10AR	Chemiluminescence Chemiluminescence
		HCl	TECO15 TGM 555	GFC Wet Chemical
		THC	Ratfische RS55 Ratfische RS55	Hot FID Hot FID
		Moisture	Beckman 865/TECO 900 dilution system	NDIR
Spray Dryer Absorber Outlet (SDO)	IMET	CO_2	Infrared IR702	NDIR
		SO_2	Western Research 721A	NDUV
		HCl	TECO 15	GFC
Fabric Filter Outlet (FFO)	IMET	O_2	Taylor OA269	Polarographic
		CO_2	Infrared IR702	NDIR
		SO_2	Western Research 721A	NDUV
		HCl	Bodenseewerk	GFC
		THC	JUM VE7	Hot FID
		CO	Infrared IR702	NDIR

NDIR - non-dispersive infra-red
NDUV - non-dispersive ultra-violet
GFC - gas filter correlation
FID - flame ionization detection

Flue gas molecular weight was determined by Integrated Orsat (EPA Method 3). Integrated bag samples of gas were collected over the course of each test run at the SDI and FFO locations. The Orsat probe was attached to the particulate sampling probe. A lung sampling system collected the integrated stack gas sample into a Tedlar bag at a rate of 0.1 l/min.

Method 5 Train (M5) was modified for the collection of particulate matter and metals (including mercury). The sample train was operated as a Method 5 particulate train with modification to the impinger configuration to enhance the collection of the metals of interest (Fig. 4-1-A). Additional preparation for this train and associated sample containers included precleaning for metals collection. Particulate collected on the filter and in the probe was weighed to determine particulate loading and then analyzed for the metals of interest.

Particle size determination was conducted at the FFO using Andersen Mark III impactors. Three runs of different durations were conducted during the test program. Nozzle sizes for the first two runs were selected to maintain a flow rate through the impactor of 0.44 cubic meter per hour. The nozzle size was increased to maintain an impactor flow rate of 1.3 cubic meters per hour for the third test, since the very low grain loading at the FFO required a long sampling time to collect 50 mg of particulate. Gas flow was monitored and recorded by observing the pressure drop across a calibrated orifice. The total dry gas volume sampled was determined using a calibrated dry gas meter.

Flue gas samples for the determination of **hexavalent chromium** concentrations were collected for three runs in accordance with the protocol in the State of California Air Resources Board (CARB) Method 425. This procedure calls for the collection of particulate matter utilizing EPA Method 5, as shown in Figure 4-1-C, then dividing the sample into equal portions to determine total chromium and hexavalent chromium.

Modified Method 5 (MM5) sampling trains were used for the collection of **polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans (PCDD/PCDF)**, and for other trace organics. A schematic of the MM5 sampling train is shown in Figure 4-1-B.

During the performance tests, 13 MM5 runs were made at the SDI location, 14 runs at the FFO location, and 4 runs at the air preheater inlet. Each run lasted approximately 4 hours to ensure the collection of at least 3 m^3 (105 dscf) of sample gas. The sampling start/stop times for each location were coordinated as closely as possible to ensure near simultaneous sampling.

During recovery of the MM5 trains, an aliquot of approximately 30 mL was removed from the condensate impinger for subsequent HCl analysis. It served as backup to the continuous HCl monitors.

The flue gas was sampled for **Volatile Organic Compounds (VOC)** during each of the 14 performance tests. During each test, three VOC runs were conducted at the FFO. The volatile organic sampling train (VOST) was operated in accordance with EPA Method 0030. The train consisted of a glass-lined probe with a glass wool plug to remove particulate matter, followed by an assembly of condensers and organic resin traps as illustrated in Figure 4-2.

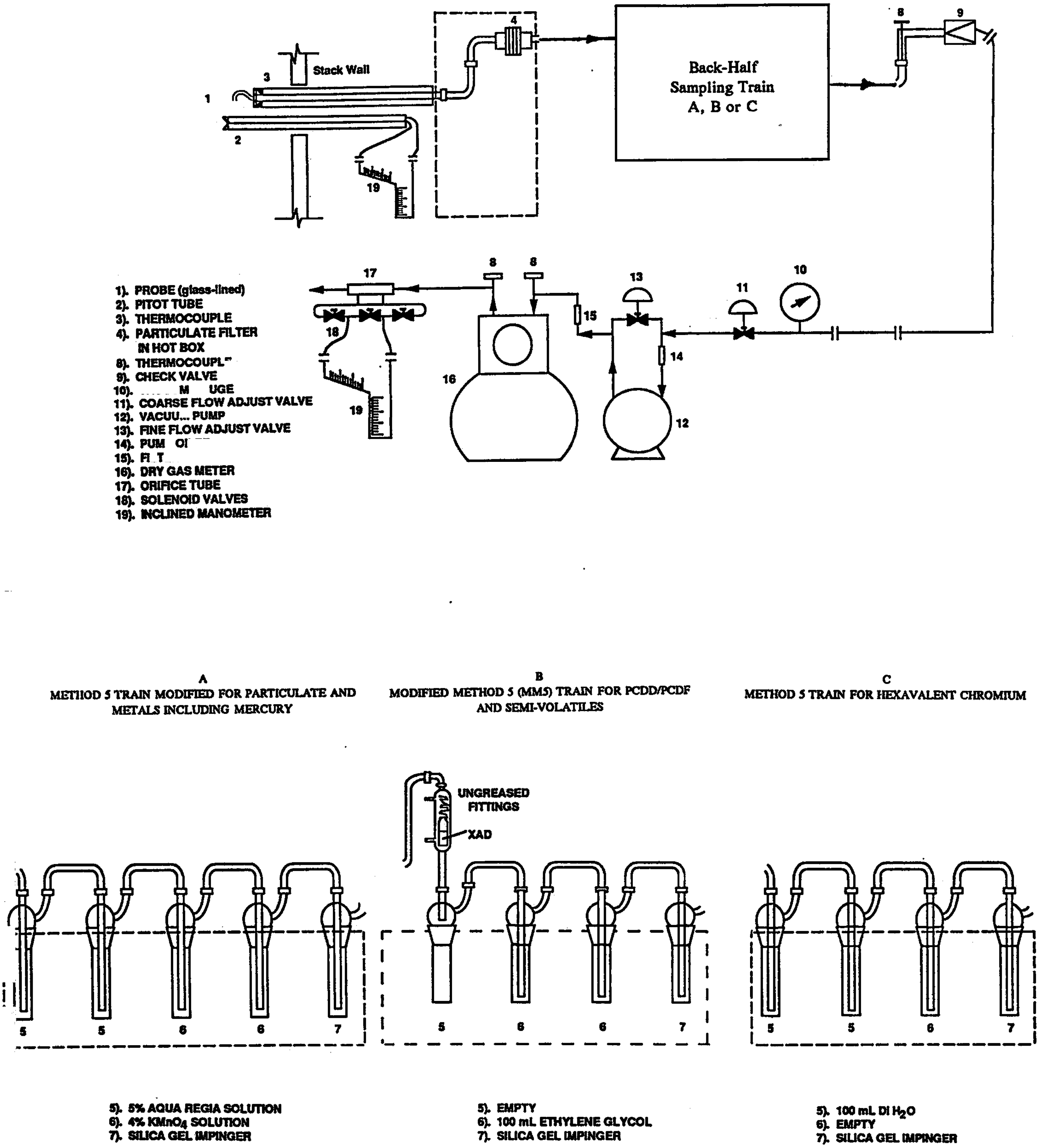


Figure 4-1. Schematic of Sampling Trains

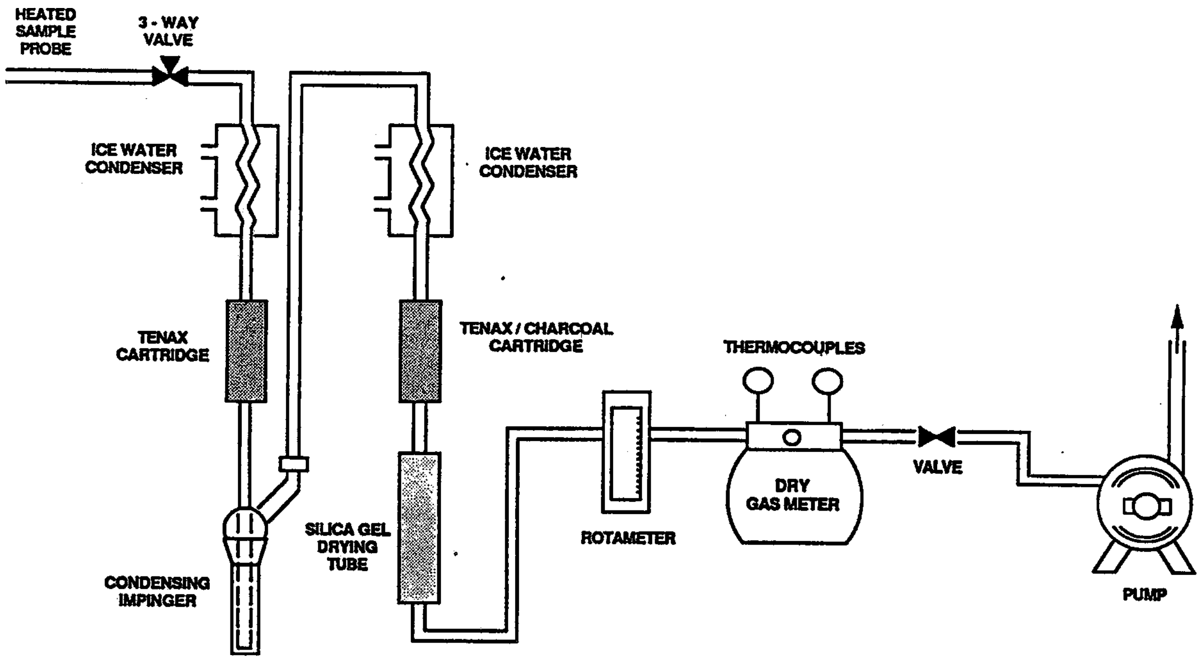


Figure 4-2. Volatile Organic Sampling Train Schematic

4.4 PROCESS PARAMETER MEASUREMENTS

During each test, all facility operating parameters were continuously monitored in the control room by appropriate program personnel, using the project data acquisition system, which recorded the process and continuous emissions data for the parameters listed in Table 4-2.

These data assisted in identifying whether the process was operating as planned or was experiencing changes or upset conditions. Carbon monoxide (CO) and oxygen (O_2) levels represented the most frequently utilized control parameters. Changes in these values initiated a review of the incinerator's primary process control parameters together with a visual inspection of the combustion chamber.

Visual inspections of the furnace burning zone were frequently carried out by the combustion expert to determine whether the burn was occurring evenly on the grates. If unusual conditions were noted, adjustments to the control system were made by the operators to avoid burning conditions that were outside the selected target. Observations of the furnace burning zone were generally made every half hour with special aspects and unusual conditions noted in the log book. During periods of abnormal operation, observations were made as frequently as every 5 to 10 minutes.

Visual inspection of the ash discharged from the incinerator to the quench tank and on the drag chain conveyor from the quench tank was part of the furnace observation routine. The primary purpose of this observation was to identify if and when ash quality was deteriorating.

Table 4-2. Major Process and Emission Parameters Monitored

Process Parameters	Continuous Emission Data
• steam and air flows • steam pressure and gas pressure drops • combustion chamber temperatures • boiler air supply and air distribution • flue gas composition • flue gas temperatures (SDI, SDO, and FFO) • outlet temperature of the spray dryer • lime slurry feed rate • acid gas removal	• carbon monoxide • oxygen • carbon dioxide • sulphur dioxide • hydrogen chloride • total hydrocarbons • nitrogen oxides

4.5 DATA ACQUISITION SYSTEM (DAS)

The complexity of this project required a sophisticated and well planned data acquisition system (DAS) which integrated data gathering, reduction, validation, and reporting procedures.

With regard to **data gathering**, the DAS was designed to automatically retrieve all outputs from instrumentation, including process data, on a continuous basis and to ensure that this information was correctly stored on a hard disk. As a backup, a hardcopy of averaged values was printed every 6 minutes. The system could also recall previously recorded information.

Linked in a network configuration, five microcomputers monitored the following instrumentation:

- the continuous gas analyzers and status;
- the exhaust gas thermocouples and pressure drop (velocity) measurement;
- combustion air temperature;
- the facility process controller, with its instrumentation and set-point values.

Data acquisition software was custom-designed to:

- continuously receive data from the data logging equipment at 30-second intervals for the CEM data and 90-second intervals for the process data, from approximately two hours before the start of each test until approximately one hour after test completion;
- convert and store the data in a standard numeric format;
- display statistics, a process schematic, and graphical summaries on a real-time basis;
- provide access to the data from a remote location via modem.

For **process monitoring** 43 process points were monitored by the DAS through the facility controller. Four important process parameters were calculated: combustion efficiency, flue gas heat loss, excess air, and steam efficiency. These values were recalculated after every scan, and the current values displayed along with the maximum, minimum, and 6 minute rolling average values.

The constant availability of data proved invaluable during the test program, because it allowed quick identification of process upsets. The data replay feature clearly provided a better understanding of the process and emission trends.

QA/QC procedures for the Data Acquisition System were substituted. Continuous emissions data were monitored by project staff and verified by QA/QC personnel to ensure that data sent corresponded to data received and stored. Zero and calibration voltages were recorded for each CEM prior to and after each test. A comparison was made between pre-test and post-test voltage readings to determine if the percentage drift was within acceptable limits. These data were reviewed by QA/QC personnel. For each Performance Test, a report containing 6-minute averages, graphics, and statistics (average, minimum, and maximum for each CEM channel) was provided to project staff for review.

Data processing involved reworking the data retrieved during the test runs into a more meaningful form (i.e., producing 6-minute averages, graphics revealing trends in process parameters and a summary report). Any problems were identified, noted, and accounted for. The overnight turnaround of data greatly assisted the team in evaluating the success of previous tests and in determining new operating conditions for the following tests. All comments from the QA/QC personnel were reviewed and any necessary corrections were made the following day. In this manner, many potential problems were avoided in the field.

Datalogger summary reports from the data processing included the following:

- Calibration Matrix report, documenting the detailed history of the state of the nine continuous stack gas monitoring instruments over the duration of each test run;
- Interval Average reports for each datalogger, displaying the 6- and 30-minute averages of selected channels over the duration of the test run;
- Channel Descriptions and Statistics report, displaying the average, maximum, minimum, percent variance and standard deviation for all process and instrumentation data;
- Summary presentation of steam characteristics, primary and secondary air flow rates and distributions, grate speeds, and boiler temperatures.

The data manually recorded on the sampling train field sheets for each sampling train were entered into the computer (along with sample recovery data from the field laboratory) and processed overnight for each test run. Summary reports were available on a daily basis for each test run. Between successive tests, eleven different graphs were produced, combining process and continuous gas data. Anomalies were investigated and corrections made as required. Following performance testing, all data were verified and corrected as required.

4.6 LABORATORY ANALYTICAL PROCEDURES

4.6.1 General

Each sampling train used in this program required a distinct sample recovery technique. The techniques used generally followed the procedures detailed in the respective sampling protocol (i.e. EPA, ASME, CARB).

One notable variation for the trace organic sampling train (MM5) was the use of ethylene glycol in the second impinger for consistency with previous NITEP programs. Additionally, the back half components were soaked once with acetone and once with hexane to improve recovery of the trace organic compounds from these components. These were deviations from the Quality Assurance Project Plan (QAPP) submitted for this program.

Another deviation from the original QAPP was HCl sampling. During recovery of the MM5 trains, an aliquot was removed from the condensate impinger for subsequent HCl analysis, as backup to the continuous HCl monitors.

For the particle size distribution samples, sufficient quantities of particulate were not collected to provide measurable cutpoints, due to the very low grain loading. The filter substrates were photographed and a qualitative assessment of each substrate was done.

A chain-of-custody procedure was established to document the identity of sample handling from first collection as a sample until analysis and data reduction were completed. Custody records traced a sample from its collection through all transfers of custody until it was transferred to the analytical laboratory. Internal laboratory records documented the custody of the sample from its collection through its disposition.

4.6.2 Analytical Protocols

The analytical laboratories responsible for each parameter and appropriate methodologies used are given in Table 4-3.

To determine the **calorific value** of the RDF, a weighed sample was burned in an oxygen bomb calorimeter under controlled conditions and the calorific value was computed from temperature observations made before and after combustion.

The **trace metals** that were analyzed in each sample are listed in Table 4-4. Prior to conducting the metal analyses, it was necessary to release the analytes of interest from the environmental matrix in which they were held, so that the final analytes in the digestate were stable and so that interferences of organics and other possible analytes were eliminated or minimized. For this program, digestions were accomplished using the 3000 Series Digestion Methods as listed in EPA SW846.

Table 4-3. Analytical Responsibilities and Methods - Performance and Characterization Testing

Parameters	Method	Analytical Laboratory
Trace Organics	ASME/Environment Canada	Environment Canada
Volatile Organics	SW-846 5040/8240	Clean Harbors Analytical Services
Chlorides		
- Impinger Solutions	Ion Chromatography	Canviro Laboratories
All Metals (excluding As, Se, Hg, and Chromium in Gaseous Streams)	SW-846 - Method 6010	Canviro Laboratories
Hexavalent Chromium	CARB Method 425	Canviro Laboratories
Arsenic	SW-846 - Method 7061	Canviro Laboratories
Selenium	SW-846 - Method 7741	
Mercury	SW-846 - Method 7470	
Higher Heating Value of RDF	ASTM E711-81	Canviro Laboratories
Ultimate Analysis of RDF	ASTM D3176/E791	
Proximate Analysis of RDF	ASTM D3172/E791	
Available Lime	ASTM C25	
Combustibles in RDF	ASTM/E791	
Moisture in RDF/Ash	ASTM E790/D3173	
RDF Particle Sizing	ASTM E828	

Table 4-4. Trace Metals List

Aluminum	Al	Manganese	Mn
Antimony	Sb	Mercury	Hg
Arsenic	As	Molybdenum	Mo
Barium	Ba	Nickel	Ni
Beryllium	Be	Phosphorus	P
Bismuth	Bi	Selenium	Se
Cadmium	Cd	Silicon	Si
Calcium	Ca	Silver	Ag
Chromium	Cr	Sodium	Na
Cobalt	Co	Tellurium	Te
Copper	Cu	Tin	Sn
Indium	In	Titanium	Ti
Iron	Fe	Vanadium	V
Lead	Pb	Zinc	Zn
Magnesium	Mg		

Aqueous and solid samples were prepared for atomic absorption (AA) or inductively coupled plasma (ICP) using the digestion procedures outlined in SW846 Method 3010 and Method 3050 for aqueous and non-aqueous samples and Method 3060 for refuse and ash. Flue gas samples for metals analysis were prepared in accordance with the procedures specified in the EMB protocol (Volume III, Appendix D of this report series).

One notable exception in the analytical procedure used for mercury is the use of potassium permanganate at six-percent concentration (as opposed to five-percent concentration in EPA Method 7470) and potassium sulfate at saturation (as opposed to five-percent concentration in Method 7470). These were added to further oxidize the sample and minimize interferences from anions such as chloride and sulfide.

Arsenic was analyzed using a gaseous hydride atomic absorption procedure as outlined in SW846, Method 7061, with the following minor modifications. Hydrochloric acid and sodium iodide were used in place of stannous chloride to reduce the arsenic to its trivalent form (APHA Method 303E, 16th Edition).

Chlorides were determined using ion chromatography. An aliquot from the MM5 train condensate (first impinger) was injected into a stream of 4-hydroxyl benzoic acid eluent prior to entering a separation column. The separated anions were measured on a conductivity detector and identified based on their retention time relative to known standards. Quantification was based on peak area single electronic integration.

Particulate samples (front half acetone rinse and the filter) collected from the particulate/metals train underwent **gravimetric analysis** prior to being submitted for metals analysis. The gravimetric analysis followed the procedures outlined in EPA Reference Method 5. The gravimetric analysis requires measuring the weight gain on the particulate filter and the residue left over in the acetone rinse of the front half train components. The gravimetric analysis requires desiccation of the samples prior to weight determination. Samples were weighed to a constant weight of ± 0.5 mg.

Environment Canada laboratory analyzed RDF, ash, and flue gas samples for **semivolatile trace organics** including PCDD/PCDF. All samples generated during two of the runs were selected for high resolution gas chromotography/mass spectroscopy (GC/MS). Several other flue gas samples (MM5) were selected for analysis by high-resolution GC/MS. Some of the dry bottom ash and grate sifting samples were combined for analysis. Two runs were analyzed separately. Table 4-5 lists the target semivolatile organic analytes in this program.

Volatile organic components (VOC) of the gaseous streams were analyzed from each VOST run. The samples collected from each VOST run consisted of a Tenax cartridge and a Tenax/charcoal backup cartridge. For every third run, the condensate impinger sample was recovered.

Tenax tube samples were analyzed for volatile organics using the thermal desorption GC/MS procedures specified in Method 5040 of SW-846. Condensates were analyzed using Method 8240 via purge-and-trap GC/MS. The list of volatile analytes is presented in Table 4-6.

Table 4-5. Target Semivolatile Organic Analytes

Compound Group	Analytes
Polychlorinated dibenzo-p-dioxins(1)	TCDD P5CDD H6CDD H7CDD OCDD
Polychlorinated dibenzofurans(1)	TCDF P5CDF H6CDF H7CDF OCDF
Chlorobenzenes	C13-6 Benzene
Polychlorinated Biphenyls	C12-10 Biphenyl
Chlorophenols	C12-5 Phenol
Polycyclic Aromatic Hydrocarbons	Acenaphthylene Acenaphthene Fluorene 2-Methyl-Fluorene Phenanthrene Anthracene Fluoranthene Pyrene Benzo (a) Fluorene Benzo (b) Fluorene 1 Methyl-Pyrene Benzo(ghi)Fluoranthene Benzo (a) Anthracene Chrysene Triphenylene 7 Methyl-Benzo(a) Anthracene Benzo (b) Fluoranthene Benzo (k) Fluoranthene Benzo (e) Pyrene Benzo (r) Pyrene Perylene 2-Methyl-Benzo (j) Aceanthrylene Indeno (123-cd) Pyrene Dibenzo (ah) Anthracene Benzo (b) Chrysene Benzo (ghi) Perylene Anthanthrene

(1) Congeners with the 2,3,7,8 configuration were analyzed by high-resolution GC/MS in selected streams from selected test runs.

Table 4-6. List of Volatile Organics

Bromodichloromethane
Bromoform
Carbon tetrachloride
Chloroethane
Chloromethane
Dibromochloromethane
1,2-Dichloroethane
trans-1,2-Dichloroethylene
1,2-Dichloropropane
Methylene chloride
Tetrachloroethylene
1,1,1-Trichloroethane
Trichloroethylene
Vinyl chloride
Benzene
Bromomethane
Chlorobenzene
Chloroform
cis-1,3-Dichloropropene
1,1-Dichloroethane
1,1-Dichloroethylene
trans-1,3-Dichloropropene
Ethylbenzene
1,1,2,2-Tetrachloroethane
Toluene
1,1,2-Trichloroethane
Trichlorofluoromethane

4.7 STATISTICAL DATA ANALYSIS

Since all sampling and laboratory results and process measurements were entered into the computer via the data acquisition system described above, an extensive matrix of data for each performance test was produced. Accordingly it was possible to perform statistical analysis of this data using the technique of regression analysis. This technique generates a mathematical model that best describes the relationship between sets of data.

Single regression analysis was first used to screen the database for relevant trends and correlations. The initial screening was for relevant linear relationships between pairs of variables. In most research, it is difficult to find a regression line, especially a straight one, which perfectly fits the data. A measure of the "goodness of the fit" is given by the correlation coefficient, R, and its square, the determination coefficient, R^2. The determination coefficient is often used in statistics because it is always a positive value, thus providing a convenient way of comparing the "goodness of fit" of different regression models. Furthermore, R^2 describes the portion of the total variance which is explained by the correlation with a value of one representing a "perfect fit".

For this project, it was decided to focus on relationships with R^2 values of greater than 0.5. For this program, regression analysis was based on 13 test runs and the critical R^2 value for 13 pairs of data for a 5 percent significance is 0.306. Therefore, the use of 0.5 as the low end cut-off for determination coefficients is within the 95% confidence interval.

Subsequent to an initial screening based on single linear regression, multiple regression correlations were generated using the Statistical Analysis System (SAS) computer package. SAS examines all possible combinations of independent variables and selects the group of variables which shows the best relationship with a dependent variable (i.e. highest R^2).

The results of the statistical analyses are presented in Chapter 5 for the combustion system and Chapter 6 for the air pollution control system.

4.8 QUALITY ASSURANCE / QUALITY CONTROL

Due to the broad program scope and the number of parties involved in the project team, considerable effort was made to blend the activities of all parties together to ensure a high level of Quality Assurance / Quality Control (QA/QC). Alliance Technologies Corporation established its own internal QA/QC program in parallel with an independent external QA/QC program coordinated by the US EPA's Emission Measurements Branch.

In general, the QA/QC personnel were responsible for overseeing all sampling and analytical aspects of the test program to ensure the sample quality. Table 4.7 summarizes the responsibilities for the internal and external QA/QC activities. Briefly, QA/QC activities included:

- ensuring compliance with accepted EC/EPA test methods;
- ensuring a thorough understanding of all methods on the part of the respective operators and sample handlers, and adherence to recommended equipment procedures and their corresponding calibration;
- verifying that all equipment was functional, proofed, and calibrated to obtain the desired data quality;
- ensuring that all test personnel understood the procedures that they followed, and subsequently regularly verifying during the test that the procedures were followed correctly;
- ensuring sample integrity for analysis throughout collection, recovery, and transfer;
- ensuring the quality of the data collected through data acquisition and processing;
- collecting duplicate samples for the various test processes, for independent analysis; and
- verifying laboratory procedures for organic and inorganic analysis.

The purpose of setting quality assurance objectives was to ensure that data of known and acceptable quality was produced. EPA, Environment Canada and Alliance Technologies collaborated to develop the Quality Assurance Project Plan (QAPP), which defined QA/QC criteria, such as levels of precision, accuracy, representativeness, completeness and comparability. These allowed for an adequate evaluation of the tests. QA criteria were developed for the following critical analyses: metals, chloride, dioxins/furans, and calorific value. Laboratory and field blank samples were taken and analyzed to provide a quantitative assessment of the occurrence of sample contamination.

Table 4-7. External and Internal QA/QC Responsibilities

Subject	Internal QA/QC Responsibility	External QA/QC Responsibility
Test Program	Define program objectives and design test matrix to achieve program objectives.	Assess if sampling program and data collection are sufficient to meet program objectives.
Test Protocols	Select protocols, detail procedures, and define QC activities and limits.	Review and critique protocols and procedures. Assess protocols for comparability to previous programs.
Calibration of Test Equipment	Verify accuracy of calibration. Document instrument performance.	Observe personnel, equipment, and procedures during performance of calibration procedures. Review documentation of instrument calibration performance. Provide on-site audit checks and document performance.
Sampling Locations	Identify suitable sampling locations and perform necessary modifications.	Check for suitability of location to permit collection of representative samples.
Field Sampling	Provide trained test crew, properly prepared and/or calibrated equipment, and sufficient supply of correct contamination-free reagents.	Observe testing, including leak checks, and document any deviations from protocols. Verify calibration by conducting on-site audits.
CEMS Testing	Document instrument performance and verify accuracy of calibration gases. Provide and follow detailed operating and QC procedures.	Review documentation on instrument performance and calibration gas analysis. Observe on-site testing and document any deviations from protocol. Conduct cylinder gas audits.
Data Acquisition System	Establish standard operating procedures and conduct routine QC checks to verify accuracy of program.	Observe operation of system. Perform audit of system by providing a known data set. Document results.
Process Samples	Provide trained/experienced personnel, acceptable sampling equipment, data sheets for documentation, and establish sample handling and sample preparation procedures.	Review sampling sites, sampling equipment, sample handling, and sample preparation protocols, as well as document activities during sampling. Observe efforts for deviations.
Sample Recovery	Recovery following defined protocols. Collect reagent blanks and field blanks.	Observe and document recovery operation. Document that correct reagent blanks and field blanks are collected.
Sample Custody	Samples logged, chain-of-custody sheets prepared, and samples properly packaged for transportation.	Review sample log-in and chain-of-custody documentation. Observe and document sample packaging. Obtain split samples for external QA/QC laboratory analysis.
Process and Field Sampling Data	Provide experienced DAS operator(s), reliable hardware, and validated software.	Document accuracy of logged data and verify accuracy of reported and calculated values with technical system audits.
Sample Analysis	Select acceptable methods and detail procedures and changes. Detail laboratory QC including calibrations, control samples, and matrix spikes.	Review and comment on selected procedures. Review performance and document deviations from selected protocol. Conduct performance evaluation audits. Submit split samples for external laboratory analysis.
Data Reduction Procedures	Establish standard data reduction procedures. Conduct initial checks on procedures/calculations to verify accuracy.	Review data reduction procedures. Perform audit of procedures/calculations using known data set and document results.

Results of the QA assessment of the chemical analyses of all samples are provided in Chapter 7 of Volume II.

The QA/QC program represented a significant effort and expenditure of resources for the project. It provided both internal and external control over all elements and activities of the test program. It provided assurance for sample quality and assisted in immediate identification of potential problems.

The findings of both the internal and external QA/QC programs indicated that the field study was executed properly, according to the stated sampling and analytical protocols, using properly calibrated and/or proofed equipment. Samples collected during this test program were deemed to be representative and the data reported was complete and accurate. To the best of the QA/QC auditors' knowledge, any errors, omissions and problems are correctly documented in the reports.

A more extensive discussion of the QA/QC program and results can be found in Chapter 7 of Volume II and in Volume VI of the report series.

5 PERFORMANCE TEST SERIES FOR COMBUSTION SYSTEM

5.1 OVERVIEW

This section summarizes the performance test (PT) results and key findings for the combustion system. In Chapter 6, PT results for the air pollution control system are provided.

The performance test series was conducted during the period from February 14 through March 1, 1989. As described earlier, 13 PT test runs were successfully conducted using 7 different test conditions for the combustion system. One full day was required for each run. The test crew used run PT-01 as a "practice" run to trouble-shoot and evaluate the sampling system. Because data from the run PT-01 are incomplete, it is not included in this report. Volume IV of the test report series presents all the data generated during the test program.

As discussed in Chapter 3, the objective of the PT Series was to evaluate the combustion system and air pollution control system under different operating conditions. Load (steam flow rate) and combustion air flow rates/distributions were the primary independent variables for combustion performance tests. The target test conditions for the performance tests evolved from the characterization test phase, but it was necessary to modify these during the PT Series due to changes in plant operation and performance. Figure 5-1 summarizes the 7 operating conditions tested for the combustion system, indicating key operating parameters for each of the 13 test runs.

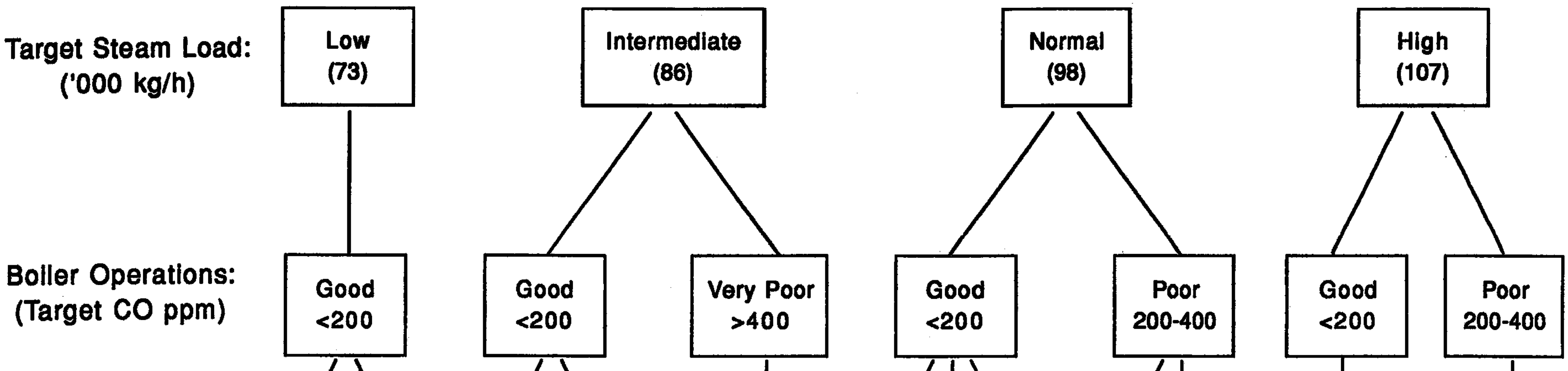
A major goal of this project was to determine trace organic and metal emissions under different process operating conditions. To account for the inherent variation in the flue gas characteristics, multiple PT runs were conducted for four of the seven combustion test conditions. Single test runs were performed for only three of the test conditions.

Some of the key findings determined from an analysis of the test data for the combustion system are listed below and are discussed in more detail in this report section:

- Good combustion conditions resulted in a 96 percent net destruction efficiency for trace organics as determined by a comparison of the total quantified organics in the facility input (RDF feed) and output (ash and stack emission) streams. The net average destruction in quantified organics for poor combustion tests was 90 percent.

- When comparing CO emissions with PCDD/PCDF emissions, the arithmetic average of CO emissions over the testing period provided the best correlation with PCDD/PCDF concentrations at the spray dryer inlet. However, the correlation was poor where CO averaged below 200 ppm for the test period. Other comparisons of PCDD/PCDF concentrations with the number or magnitude of CO spikes and the percent of time above an absolute CO level produced less significant correlations.

- For poor combustion conditions, average total hydrocarbons (THC) or CO emission is the best single indicator of **uncontrolled** PCDD/PCDF emissions, with determination coefficients, R^2 of 0.97 and 0.95 respectively.



PT Number:	PT 13	PT14	PT 10	PT 2	PT 5	PT 9	PT 8	PT 11	PT 3	PT 4	PT 7	PT 12	PT 6
Steam ('000kg/h)	71	74	87	88	84	95	96	96	98	99	101	108	106
CO Target (ppm)	<100	<100	<100	<100	>400	<100	<100	<100	400	200	200	<100	<100
CO Actual (ppm)	155	72	85	111	863	93	90	87	380	215	347	112	390
TOFA	2	2	2	2	1	2	2	2	1	3	3	2	2
RW OFA(kPa)	-	-	-	-	8.8	8.8	8.8	8.8	8.8	-	-	8.8	-
FD Fan (kPa)	2.5	2.5	<3.8	<3.8	2.8/3.8	3.3	3.3	3.8	3.8	3.8	3.3	4.3	4.0
%OFA	47	49	52	52	38	51	48	52	44	54	51	53	57

Figure 5-1 Performance Test Key Operating Parameters For Combustion System Test Series

- For good combustion conditions, entrained particulate matter at the SDA inlet is a fair indicator of **uncontrolled** PCDD/PCDF emissions ($R^2 = 0.60$).

- Previous laboratory and field tests have shown that PCDD/PCDF concentrations increase when the flue gases pass through the 400 - 150°C temperature range. Contrary to earlier findings, the PCDD/PCDF emissions decreased when the flue gases passed through this range. This reduction may be related to the rapid cooling and/or the relatively short time the particulate matter was held at this range. The flue gas passes through this range in the air preheater which has a short residence time of 1.5 - 2 seconds.

- The best multiple regression **prediction models** for **uncontrolled** trace organic emissions typically employ two or more CEM variables which characterize or identify the combustion process (i.e., CO, NO_x, HCl, furnace temperatures, and moisture).

- The best multiple regression **control models** for **uncontrolled** trace organic emissions typically employ two or more combustion operation variables which impact lower furnace combustion conditions (i.e., undergrate air flow, rear wall air flow, moisture, and total combustion air).

5.2 SUMMARY BY PERFORMANCE TEST RUN

Tables 5-1 and 5-2 summarize some of the key data generated during each PT run for the combustion system. Key process data for the combustion system are presented in Table 5-1 per test run. Parameters shown here include combustion parameters, feed and ash mass rates, and flue gas flow rates. Table 5-2 presents some of the flue gas data measured at the SD inlet per PT run. Detailed test results per PT run are presented in Volume II of the report series including the organic and metal analyses of the RDF feed stream and the various ash streams leaving the combustor, as well as trace organics and metal analyses for the flue gas at the air preheater inlet, SD inlet, and FF outlet.

The test runs are categorized by the steam load (low, intermediate, normal, or high) and combustor operation (good, poor, or very poor).

Combustor operation is rated by the average CO level for the run, measured at the SD inlet, as follows:

good:	≤ 200 ppm
poor:	> 200 ppm and ≤ 400 ppm
very poor:	> 400 ppm.

5.3 SUMMARY BY PERFORMANCE TEST CONDITION

Key performance test data for the combustion system for each of the 7 operating conditions are shown in Appendix A. These data are discussed in small segments in this section of the report.

TABLE 5-1. KEY PROCESS DATA FOR COMBUSTION SYSTEM PER PT RUN

STEAM LOAD		LOW		INTERMEDIATE			NORMAL			NORMAL			HIGH	
COMBUSTOR OPERATION		GOOD	GOOD	GOOD	GOOD	VERY POOR	GOOD	GOOD	GOOD	POOR	POOR	POOR	GOOD	POOR
TEST #		PT-13	PT-14	PT-10	PT-02	PT-05	PT-09	PT-08	PT-11	PT-03	PT-04	PT-07	PT-12	PT-06
STEAM FLOW	('000 kg/h)	71	74	87	88	84	95	96	96	100	99	101	107	106
REFUSE FEED RATE	('000 kg/h)	20.7	18.9	26.1	27.6	27.0	30.4	28.7	25.4	30.8	30.7	26.4	28.0	27.5
RW O/F AIR	('000 kg/h)	0	0	0	0	1.5	3.6	3.6	3.6	3.8	0	0	3.2	0
TANGENTIAL O/F AIR	('000 kg/h)	39	43	51	51	32	49	46	51	39	63	56	52	66
TOTAL O/F AIR	('000 kg/h)	45	49	56	56	40	59	56	60	48	69	62	61	72
TOTAL COMB. AIR	('000 kg/h)	94	99	109	109	103	116	117	116	110	127	121	116	126
GRATE SPEED		17/19	15/17	15/19	37	23/18	27/23	29/27	18	19	20	27/23	29	27
F.D. FAN PRESSURE		9/10	10	14	15	15/11	13	15/13	15	15	15	13	18	16
AIR DISTRIBUTION														
UG AIR	%	53	51	48	48	62	49	52	48	56	46	49	47	43
PDA AIR	%	5.8	5.9	5.3	4.6	6.1	5.3	5.4	5.0	5.1	4.5	4.7	5.0	5.1
RW AIR	%	0	0	0	0	1.5	3.1	3.1	3.1	3.5	0	0	2.7	0
TANGENTIAL AIR	%	42	44	47	47	31	42	40	44	35	50	46	45	52
O/F AIR	%	47	49	52	52	38	51	48	52	44	54	51	53	57
PROCESS TEMPERATURES														
FURNACE TEMPERATURE	(°C)	965	1004	1012	1022	1020	1033	1015	1026	1034	1059	1006	1049	976
BOILER INLET TEMP.	(°C)	579	597	603	608	605	575	547	599	596	598	544	607	612
ECON. OUT. TEMP.	(°C)	346	365	373	355	367	371	387	374	370	371	387	387	365
A/H GAS OUTLET TEMP.	(°C)	179	193	193	192	190	193	203	187	208	193	204	197	185
TOFA ELEVATION (SETTINGS)														
– TOP	(DEG)	+10	+10	+10	+10	–	+10	+10	+10	+10	+10	+10	+10	+10
– MIDDLE	(DEG)	+6	+6	+6	+6	–/+6	+6	+6	+6	–	+6	+6	+6	+6
– BOTTOM	(DEG)	–	–	–	–	–	–	–	–	–	+2	+2	+2/–	+2
REAR OFA PRESSURE	(kPA)	–	0	0	0	8.8/0	8.8	8.8	8.8	8.8	0	0	0/8.8	0
ASH MASS RATES														
ECONOMIZER (ACTUAL)	kg/h	8.7	17	10	24	14	15	18	14	11	15	14	17	10
FABRIC FILTER (ACTUAL)	kg/h	673	1130	1170	NC	429	1320	434	2140	NC	1390	550	315	1240
TOTAL FLY ASH (ACTUAL)	kg/h	682	1150	1180	NC	443	1330	452	2150	NC	1400	564	332	1250
GRATE SIFTINGS (ACTUAL)	kg/h	85	89	91	140	103	118	100	110	125	105	116	106	71
BOTTOM ASH (WET)	kg/h	2380	2930	3410	4360	3210	3820	4370	3360	4040	4370	4610	4000	4710
FLUE GAS FLOW RATE														
AIR HEATER INLET														
MM5 SAMPLING TRAIN	Sm³/hr			137000			129000	131000				139000		
SPRAY DRYER INLET														
MM5 SAMPLING TRAIN:	Sm³/h	132000	141000	154000	151000	146000	145000	149000	145000	148000	153000	158000	143000	160000
METALS SAMPLING TRAIN	Sm³/h	123000	137000	156000	155000	148000	148000	151000	148000	147000	156000	158000	145000	162000

NC – Data not collected

TABLE 5-2. KEY DATA FOR COMBUSTION GAS COMPOSITION PER PT RUN

STEAM LOAD		LOW		INTERMEDIATE			NORMAL			NORMAL			HIGH	
COMBUSTOR OPERATION		GOOD	GOOD	GOOD	GOOD	VERY POOR	GOOD	GOOD	GOOD	POOR	POOR	POOR	GOOD	POOR
TEST #		PT-13	PT-14	PT-10	PT-02	PT-05	PT-09	PT-08	PT-11	PT-03	PT-04	PT-07	PT-12	PT-06
PREHEATER INLET														
Total PCDD	(ng/Sm³ **)			174			141	258				390		
	(mg/tonne *)			0.80			0.60	1.16				2.06		
Total PCDF	(ng/Sm³ **)			816			767	1,827				1,932		
	(mg/tonne *)			3.8			3.2	8.2				10.2		
SPRAY DRYER INLET														
**+ CO	ppm	158	70	77	108	903	92	89	68	432	214	387	116	397
CO2	%	9.8	10.1	10.5	10.4	11.0	11.9	11.8	11.6	12.0	11.9	12.1	12.9	11.5
O2	%	10.1	9.6	9.2	9.1	8.7	7.6	7.5	7.9	6.9	7.6	7.2	6.4	7.9
** NOx	ppm	157	177	186	184	149	188	193	175	160	172	172	180	157
** SO2	ppm	175	189	194	177	169	178	184	174	200	186	183	198	192
** HCl	ppm	421	442	429	472	469	432	538	413	419	471	399	470	404
** THC	ppm	6	3	2	3	52	5	3	2	20	8	13	6	29
Moisture	%	12.2	12.2	13.8	13.6	15.5	17.5	16.2	15.0	17.8	14.8	NA	16.0	14.7
Total PCDD	(ng/Sm³ **)	147	72	243	213	580	71	211	92	230	151	207	67	317
	(mg/tonne *)	0.76	0.45	1.26	1.01	2.86	0.33	1.08	0.51	1.11	0.74	1.25	0.36	1.76
Total PCDF	(ng/Sm³ **)	452	356	424	733	1281	378	951	444	778	623	796	215	885
	(mg/tonne *)	2.35	2.23	2.19	3.48	6.32	1.78	4.87	2.46	3.75	3.08	4.80	1.18	4.92
Mercury	(μg/Sm³**)	531	914	718	726	634	644	646	661	583	614	584	558	583
	(g/tonne *)	2.58	5.57	3.76	3.54	3.18	3.10	3.35	3.71	2.79	3.10	3.53	3.10	3.30
Particulate	(μg/Sm³**)	3,210,000	3,700,000	4,530,000	5,440,000	4,460,000	3,890,000	4,750,000	3,980,000	4,640,000	3,270,000	4,230,000	3,390,000	3,310,000
	(g/tonne *)	15,600	22,500	23,700	26,500	22,400	18,800	24,600	22,400	22,200	16,500	25,600	18,900	18,700

** Corrected to 12% CO2

* Refuse as fired

\+ Reconstructed from measurements at SD inlet and FF outlet.

Note that preheater inlet samples were collected only for PT-07 to PT-10.

5.3.1 Process Data

Table 5-3 presents process operating conditions for the combustor system, including steam and refuse feed rates, process temperatures, and ash rates. The steam production rate ranged from 73,000 kg/h (160,000 lb/h) for the "low load" condition to 107,000 kg/h (235,000 lb/h) for the "high load" condition. Normal production was 96,000-100,000 kg/h. Refuse feed rate was 19,000 kg/h for the low load, but the refuse rate was within a narrow range (27,000 to 30,000 kg/h) for the other loads. Accordingly, there is a poor correlation between refuse feed rate and steam production. The distinction between "good operation" and "poor operation" using CO as the parameter is clearly shown: CO is below 200 ppm for good operation and over 200 ppm for poor operation.

5.3.2 CEM Data

Test condition averages for the CEM data are given in Table 5-4 and include CO, CO_2, O_2, THC, SO_2, NO_x, and HCl at the spray dryer inlet (SDI).

The CO concentrations at the SDI are reconstructed from measurements at SDI and fabric filter outlet (FFO). Two CO analyzers were used during the test program. One was located at the SD inlet and the other at the FF outlet. The scale of the analyzer at the SD inlet ranged from 0 to 500 ppm. The analyzer at the FF outlet read values greater than 500 ppm. The most reliable data from both analyzers were used, and a new data set (corrected to 12% CO_2) was reconstructed for the CO concentrations at the SD inlet and FF outlet. If either analyzer measured less than 500 ppm CO, the reading from the analyzer at the SD inlet was used. If both analyzers read greater than 500 ppm CO, the value from the analyzer at the FF outlet was used.

Excess oxygen appears to correlate inversely with steam load (i.e. higher O_2 (10%) at low load and lower O_2 (6-8%) at higher steam load).

As expected, the SO_2 and HCl at the spray dryer inlet were not affected by combustor operation. Based on averages for each PT operating condition, inlet SO_2 was in the range of 170-200 ppm and inlet HCl ranged from 400 to 470 ppm, which is typical for MSW incinerators. Variation in SO_2 and HCl at SDI location is attributable to differences in the amount of chlorine and sulphur in the refuse feed. Control of acid gases is discussed later in report Chapter 6.

THC concentrations were significantly higher (14, 29, 52 ppm) during "poor combustor operation". THC was 2 to 6 ppm for "good operation".

5.3.3 Trace Organic Concentrations

Concentrations of trace organics measured at the air preheater inlet and spray dryer inlet are summarized in Table 5-5, for each performance test condition of the combustion system. The spray dryer inlet represents the exit of the combustion system, prior to treatment in the air pollution control system.

TABLE 5–3. KEY PROCESS DATA FOR COMBUSTION SYSTEM PER PERFORMANCE TEST CONDITION

STEAM LOAD :		LOW	INTERMEDIATE		NORMAL		HIGH	
COMBUSTOR OPERATION :		GOOD	GOOD	VERY POOR	GOOD	POOR	GOOD	POOR
TEST # :		13,14	2,10	5	8,9,11	3,4,7	12	6
Steam Rate	kg/h	73,000	88,000	84,000	96,000	100,000	107,000	106,000
Refuse Feed Rate	kg/h	19,000	27,000	27,000	28,000	29,000	28,000	28,000
UG:OF Air Ratio		1.083	0.923	1.632	1.000	1.000	0.887	0.754
TOFA Number Levels		2	2	1	2	1&3	2	2
CO	(ppm)	114	93	903	83	344	116	397
Furnace Temperature	°C	985	1,016	1,020	1,025	1,033	1,049	976
Boiler Inlet Temp.	°C	588	605	605	574	579	607	612
Economizer Outlet Temp.	°C	356	364	367	377	376	387	365
A/H Outlet Temp.	°C	186	193	190	194	202	197	185
Economizer Ash Rate	kg/h	12.7	16.7	13.8	15.5	13.5	17.0	10.5
Fabric Filter Ash Rate	kg/h	903	583	429	1,297	968	315	1,239
Bottom Ash Rate (dry)	kg/h	2,370	3,100	2,830	3,120	3,550	3,280	3,350

TABLE 5–4. CEM DATA FOR COMBUSTION SYSTEM PER PERFORMANCE TEST CONDITION

STEAM LOAD :		LOW	INTERMEDIATE		NORMAL		HIGH	
COMBUSTOR OPERATION :		GOOD	GOOD	VERY POOR	GOOD	POOR	GOOD	POOR
TEST # :		13,14	2,10	5	8,9,11	3,4,7	12	6
Spray Dryer Inlet								
Flue Gas Flow Rate	Sm³/h	133,000	154,000	147,000	148,000	153,000	144,000	161,000
Moisture	%	12.2	13.7	15.5	16.2	16.3	16.0	14.7
*+CO	ppm	114	93	903	83	344	116	397
CO2	%	10.0	10.5	11.0	11.8	12.0	12.9	11.5
O2	%	9.9	9.2	8.7	7.7	7.2	6.4	7.9
* NOx	ppm	167	185	149	185	168	180	157
* SO2	ppm	182	186	169	179	189	198	192
* HCl	ppm	432	450	469	461	430	470	404
* THC	ppm	4.7	2.5	52.4	3.3	13.9	6.1	28.6

* – Corrected to 12% CO2

\+ – Reconstructed from measurements at SD inlet and FF outlet.

TABLE 5–5. TRACE ORGANIC CONCENTRATIONS FOR COMBUSTION SYSTEM PER PERFORMANCE TEST CONDITION

STEAM LOAD :	LOW	INTERMEDIATE		NORMAL		HIGH	
OPERATION :	**GOOD**	**GOOD**	**VERY POOR**	**GOOD**	**POOR**	**GOOD**	**POOR**
TEST # :	**13,14**	**2,10**	**5**	**8,9,11**	**3,4,7**	**12**	**6**
CONCENTRATION (ng/Sm^3 @ 12% CO2)							
Preheater Inlet							
PCDD	NC	174	NC	200	390	NC	NC
PCDF	NC	816	NC	1,300	1,900	NC	NC
CB	NC	12,000	NC	12,300	14,000	NC	NC
PCB	NC	252	NC	100	269	NC	NC
CP	NC	21,200	NC	39,000	59,300	NC	NC
PAH	NC	10,500	NC	44,800	88,900	NC	NC
Spray Dryer Inlet							
PCDD	109	228	580	125	196	67	317
PCDF	404	579	1,280	591	732	215	885
CB	3,960	6,050	15,800	5,480	6,940	6,030	9,400
PCB	–	20	20	33	11	34	12
CP	13,300	14,300	114,000	14,300	24,100	16,600	41,600
PAH	3,500	7,330	112,000	16,500	53,900	16,200	88,600
REFUSE MASS RATIO (mg/tonne*)							
Preheater Inlet							
PCDD	NC	0.24	NC	0.28	2.1	NC	NC
PCDF	NC	0.19	NC	0.18	10.2	NC	NC
CB	NC	55	NC	54	74	NC	NC
PCB	NC	1.2	NC	0.4	1.4	NC	NC
CP	NC	97	NC	171	313	NC	NC
PAH	NC	48	NC	194	470	NC	NC
Spray Dryer Inlet							
PCDD	0.61	1.1	2.9	0.64	1.0	0.36	1.8
PCDF	2.3	2.8	6.3	3.0	3.9	1.2	4.9
CB	23	30	78	28	37	33	52
PCB	–	0.1	0.1	0.17	0.06	0.19	0.065
CP	76	71	560	73	127	91	231
PAH	20	36.0	552	81	281	89	493

Note: "–" denotes value below detection limit
* – refuse as fired
NC – not collected; Preheater inlet samples collected for PT07 through PT10 only.

It is relevant to note that, in general, concentrations of all trace organics at the SDI, except PCB (which is relatively low), were much higher under poor combustion conditions than under good combustion conditions. This is clearly illustrated in Table 5-6. Accordingly, combustor operations have a significant effect on trace organic concentrations in the flue gas. Removal of these pollutants by the APC system was excellent, and this is further discussed in Chapter 6.

Table 5-6. Trace Organic Concentrations (ng/Sm^3 @ 12% CO_2) before APC (after Combustion System) for Good Operation Versus Poor Operation

Trace Organic	Under Good Combustion	Under Poor Combustion
PCDD	70-230	200-600
PCDF	220-600	700-1300
CB	4000-6000	7000-16000
CP	13000-17000	24000-114000
PAH	4000-17000	54000-112000

5.3.4 Particulate/Metal Concentrations

The concentrations of particulate matter and selected trace metals from the combustor system are summarized in Table 5-7, for each performance test condition of the combustion system. The significant removal of these compounds by the APC system are discussed in Chapter 6. It is interesting to note that there is no significant difference in concentrations of particulates and trace metals between poor operations and good operations of the combustion system.

5.3.5 RDF Analysis

Ultimate and proximate analyses were performed on the RDF and are reported on a dry basis in Table 5-8. The content of trace organics and selected trace metals in the RDF are also summarized in Table 5-8, for each performance test condition. The higher heating value of the RDF was in the range of 7,800 to 9,000 Btu/lb (dry basis). The ash content of the RDF ranged from 12.5 to 18.2% (dry basis), with most results between 16 and 17%. Chlorine content was relatively broad 0.36 to 0.84%, as expected. Sulphur content was 0.19 to 0.31%. Generally, there was a very wide range in the amount of trace organics or trace metals present in the RDF samples, which is to be expected when analyzing for compounds at very low concentrations.

5.3.6 Ash Analysis

The content of trace organics in the various ash streams is summarized in Table 5-9, for each performance test condition. Data for the fabric filter ash is also provided to illustrate that trace organics are highest in the fabric filter ash and lowest in incinerator ash.

Trace metals in the various ash streams are summarized in Table 5-10, for each performance test condition. These results are further discussed later in this report.

TABLE 5-7. PARTICULATE & TRACE METAL CONCENTRATION FOR COMBUSTION SYSTEM PER PERFORMANCE TEST CONDITION

STEAM LOAD :	LOW	INTERMEDIATE		NORMAL		HIGH	
OPERATION :	GOOD	GOOD	VERY POOR	GOOD	POOR	GOOD	POOR
TEST # :	13,14	2,10	5	8,9,11	3,4,7	12	6
CONCENTRATION (µg/Sm^3 @ 12% CO2)							
Spray Dryer Inlet							
Antimony	113	120	122	135	60	173	51
Arsenic	205	240	230	211	186	247	194
Cadmium	573	584	527	694	552	562	7,440
Chromium	1,050	983	623	984	539	745	353
Copper	2,010	1,990	1,430	2,530	1,530	1,110	1,260
Lead	10,800	8,710	14,300	5,160	10,200	4,040	7,230
Mercury	723	722	634	650	594	558	583
Nickel	3,380	1,420	2,030	805	503	523	257
Zinc	48,300	44,000	31,200	44,300	35,600	34,700	31,000
Particulate	3,920,000	5,310,000	4,770,000	4,490,000	4,320,000	3,670,000	3,580,000
REFUSE MASS RATIO: (g/tonne*)							
Spray Dryer Inlet							
Antimony	0.62	0.61	0.61	0.70	0.32	0.96	0.29
Arsenic	1.1	1.2	1.2	1.1	1.0	1.4	1.1
Cadmium	3.2	3.0	2.6	3.6	2.9	3.1	2.5
Chromium	5.7	4.9	3.1	5.0	2.8	4.1	2.0
Copper	11.2	10.0	7.2	13.0	8.0	6.2	7.2
Lead	59	43	72	28	52	22	41
Mercury	4.1	3.6	3.2	3.4	3.1	3.1	3.3
Nickel	17.4	7.0	10.2	4.0	2.6	2.9	1.5
Zinc	263	223	157	230	187	193	176
Particulate	21,500	26,700	24,000	23,400	22,900	20,400	20,300

* – refuse as fired

TABLE 5–8. RDF ANALYSIS (DRY BASIS) PER PERFORMANCE TEST CONDITION

STEAM LOAD:		LOW	INTERMEDIATE		NORMAL		HIGH	
OPERATION:		GOOD	GOOD	VERY POOR	GOOD	POOR	GOOD	POOR
TEST #:		14	2–10	5	8–9–10	3–4–7	12	6
HIGHER HEATING VALUE	BTU/LB	8,525	7,985	7,813	7,930	8,187	8,434	8,995
PROXIMATE ANALYSIS:								
VOLATILE MATTER	%	70.51	72.42	72.01	71.02	73.36	73.02	75.36
FIXED CARBON	%	12.97	11.03	12.02	10.78	10.93	9.65	12.17
ASH	%	16.52	16.56	15.97	18.21	15.71	17.33	12.47
ULTIMATE ANALYSIS:								
Cl	%	0.51	0.36	0.84	0.45	0.52	0.71	0.64
C	%	50.41	47.62	44.37	47.54	46.74	48.53	50.66
H	%	4.69	6.78	6.15	5.62	5.83	5.84	5.89
N	%	0.27	0.50	0.51	0.42	0.42	0.46	0.41
S	%	0.31	0.28	0.24	0.19	0.29	0.30	0.25
ASH	%	16.52	16.56	15.97	18.21	15.71	17.33	12.47
O2 (BY DIFFERENCE)	%	27.29	27.91	31.92	27.58	30.50	27.01	29.68
MOISTURE CONTENT (as fired)	%	17.12	24.27	23.26	22.31	22.54	20.47	17.23
TRACE ORGANICS: Refuse Mass Ratio (mg/tonne*)								
PCDD		6.3	2.5	5.2	3.5	3.9	4.8	13.0
PCDF		0.170	0.087	–	0.340	0.058	0.110	0.150
CB		22.0	13.0	22.0	5.9	702.0	53.0	–
PCB		–	57	194	270	–	188	–
CP		626	473	625	452	580	558	2,278
Total PAH		57,100	5,140	4,070	4,640	5,540	11,200	8,260
TRACE METALS: Refuse Mass Ratio (g/tonne*)								
Antimony		6.5	2.1	4.7	3.8	7.9	7.3	14.0
Arsenic		1.8	2.3	2.2	1.9	4.8	3.7	1.6
Cadmium		4.3	1.5	3.0	2.1	3.5	3.0	2.0
Chromium		26	20	16	66	56	11	13
Copper		243	541	26	583	100	5,890	404
Lead		180	87	159	429	296	324	143
Mercury		0.051	0.045	0.041	0.116	0.052	0.038	0.034
Nickel		37	34	19	52	58	23	13
Zinc		455	335	206	286	167	3335	357

"–" denotes value below detection limit
* – refuse as fired
Note: No data available for PT–13; values are for PT–14 only.

TABLE 5–9. TRACE ORGANICS IN ASH PER PERFORMANCE TEST CONDITION

STEAM LOAD :	LOW	INTERMEDIATE		NORMAL		HIGH	
OPERATION : TEST # :	GOOD 14	GOOD 2,10	VERY POOR 5	GOOD 8,9,11	POOR 3,4,7	GOOD 12	POOR 6
REFUSE MASS RATIO: (mg/tonne of refuse*)							
Incinerator Ash							
PCDD	–	–	–	0.012	–	–	–
PCDF	–	–	–	0.021	–	–	–
CB	–	–	–	–	–	–	–
PCB	–	–	–	–	–	–	–
CP	1.4	1.5	1.6	0.29	1.4	–	1.7
PAH	5.7	824	8.2	1.9	20	24	17
Economizer Ash							
PCDD	–	–	0.221	0.034	–	–	0.011
PCDF	–	0.019	0.93	0.22	0.159	0.066	0.456
CB	–	–	–	–	–	–	–
PCB	–	–	–	–	–	–	–
CP	21.2	8.8	5.1	7.0	5.2	6.1	1.5
PAH	–	5.2	242	7.5	34	–	413
Fabric Filter Ash							
PCDD	11	1.2	1.5	3.3	3.5	0.23	10
PCDF	10	2.1	1.1	6.5	6.7	0.63	13
CB	103	31	17	42	34	8	76
PCB	–	–	–	–	–	–	–
CP	133	86	46	133	127	16	275
PAH	421	63	150	114	62	13	335
CONCENTRATION: (ng/g of ash)							
Incinerator Ash							
PCDD	–	–	–	0.10	–	–	–
PCDF	–	–	–	0.17	–	–	–
CB	–	–	–	–	–	–	–
PCB	–	–	–	–	–	–	–
CP	10	12	15	2.5	11	–	14
PAH	44	6,430	76	16	161	196	136
Economizer Ash							
PCDD	–	–	0.43	0.061	–	–	0.03
PCDF	–	0.029	1.83	0.38	0.35	0.11	1.2
CB	–	–	–	–	–	–	–
PCB	–	–	–	–	–	–	–
CP	24	15	10	13	11	10	4.0
PAH	–	6.0	475	14	78	–	1,087
Fabric Filter Ash							
PCDD	184	27	96	74	119	20	227
PCDF	166	47	71	139	222	56	282
CB	1,730	684	1,090	900	1,000	708	1,680
PCB	–	–	–	–	–	–	–
CP	2,220	1,920	2,870	2,730	4,160	1,450	6,100
PAH	7,030	1,400	9,440	2,920	1,900	1,160	7,430

Note: "–" denotes value below detection limit
* – refuse as fired

TABLE 5–10. TRACE METALS IN ASH PER PERFORMANCE TEST CONDITION

STEAM LOAD :	LOW	INTERMEDIATE		NORMAL		HIGH	
OPERATION :	GOOD	GOOD	VERY POOR	GOOD	POOR	GOOD	POOR
TEST # :	14	2,10	5	8,9,11	3,4,7	12	6
CONCENTRATION: (µg/g of ash)							
Dry Bottom Ash							
Antimony	1.7	–	1.1	1.9	0.4	2.1	–
Arsenic	12	10	10	10	8	14	8
Cadmium	9.1	6	6	7	7	4	5
Chromium	316	184	196	204	232	189	158
Copper	4,370	6,710	3,840	4,550	2,780	16,100	1,120
Lead	3,600	1,250	1,910	2,400	1,600	1,290	1,020
Mercury	–	0.041	–	–	0.102	0.026	0.322
Nickel	333	337	294	211	172	172	96
Zinc	1,880	1,620	1,150	1,400	1,200	1,100	1,260
Grate Sifting Ash							
Antimony	21	26	25	37	45	23	44
Arsenic	10	10	8.1	11	8.7	13	9.4
Cadmium	8.8	8.7	11	10	11	13	12
Chromium	297	409	454	282	337	192	284
Copper	3,960	9,370	956	2,340	1,540	1,620	11,500
Lead	8,550	12,900	3,880	9,730	7,710	8,560	16,800
Mercury	0.56	0.46	2.02	0.98	1.81	0.76	1.02
Nickel	432	693	1,136	401	337	253	303
Zinc	1,630	3,240	1,790	2,280	4,210	1,930	2,800
Economizer Ash							
Antimony	8.1	10	13	3.2	8.9	2.7	9.3
Arsenic	14	12	15	11	12	12	18
Cadmium	6.5	8.0	5.9	7.3	7.0	8.9	6.2
Chromium	310	245	330	400	307	210	150
Copper	1,130	660	679	1,540	606	580	509
Lead	940	785	949	923	949	979	659
Mercury	0.028	0.011	0.02	0.014	0.019	–	0.024
Nickel	660	355	1,289	377	396	260	170
Zinc	1,820	1,200	1,410	1,930	1,520	1,350	1,760
Fabric Filter Ash							
Antimony	17	10	9.0	12	8.9	8.2	10
Arsenic	21	19	15	20	18	16	19
Cadmium	98	87	70	93	93	138	96
Chromium	226	274	264	245	163	187	154
Copper	600	637	431	676	355	365	374
Lead	2,750	2,350	1,990	3,130	3,230	2,870	3,670
Mercury	45	14	25	31	43	32	36
Nickel	541	304	744	415	239	246	374
Zinc	7,870	5,880	5,460	6,970	7,830	4,810	9,790

Note: "–" denotes value below detection limit

5.4 ORGANICS: INPUT-OUTPUT ANALYSIS

Combustion is an effective means of reducing waste and of rapidly converting its organic constituents to carbon dioxide, water vapor and ash. The average net destruction efficiencies of the organics are listed in Table 5-11. The average net destruction efficiency was determined by first subtracting the mass rate of the inputs minus the sum total mass rate of the outputs and dividing by inputs. Negative values such as those noted for PCDF indicate a net increase (formation) of a particular class of compounds. For all organics except chlorobenzene, greater destruction is achieved for good combustion than poor combustion. An overall net destruction efficiency for the combined tests was found to be 94.5%. Similar results were obtained for the net destruction efficiencies of samples from Quebec City combustion tests (Environment Canada, 1988). The Quebec City unit is a mass burn municipal waste incinerator with an electrostatic precipitator (ESP). Figure 5-2 shows the input/output for each stream for dioxins and furans in graphical form. Each bar in the graphs represents the average amount (mg/h) of quantified organic material found in each stream during these tests. Note that the incinerator ash, economizer ash and stack emissions show virtually no visible bars. Also note slightly greater output levels of organic material during poor combustion as compared to good combustion.

Table 5-11. Destruction of Organics by Combustion

Organics	Poor Combustion 5 Tests	Good Combustion 7 Tests	Combined Conditions 12 Tests
PCDD	74.3%	80.6%	77.3%
PCDF	-6668%*	-1076%*	-2143%*
PCDD/PCDF	-2.2%*	17.0%	7.1%
CB	88.1%	-81.6%*	79.4%
PCB	99.8%	99.95%	99.9%
CP	74.8%	84.4%	78.8%
PAH	93.2%	97.2%	96.0%
Average	90.5%	96.4%	94.5%

* indicates formation

5.5 NITROGEN OXIDES FORMATION

In modern municipal waste combustors, there is a general tendency to produce higher temperatures and better mixing in the combustor to reduce carbon monoxide (CO) and organic emissions. The higher temperatures and better mixing also lead to higher NO_x emissions. Figure 5-3 illustrates the trade-off between CO and NO_x emissions. This Figure contains 30 second readings from the continuous emission monitors for performance tests 3 and 9. For both good and poor combustion tests, low NO_x emissions correspond to high CO emissions and low CO emissions correspond to high NO_x emissions. Figure 5-4 shows the test average CO versus

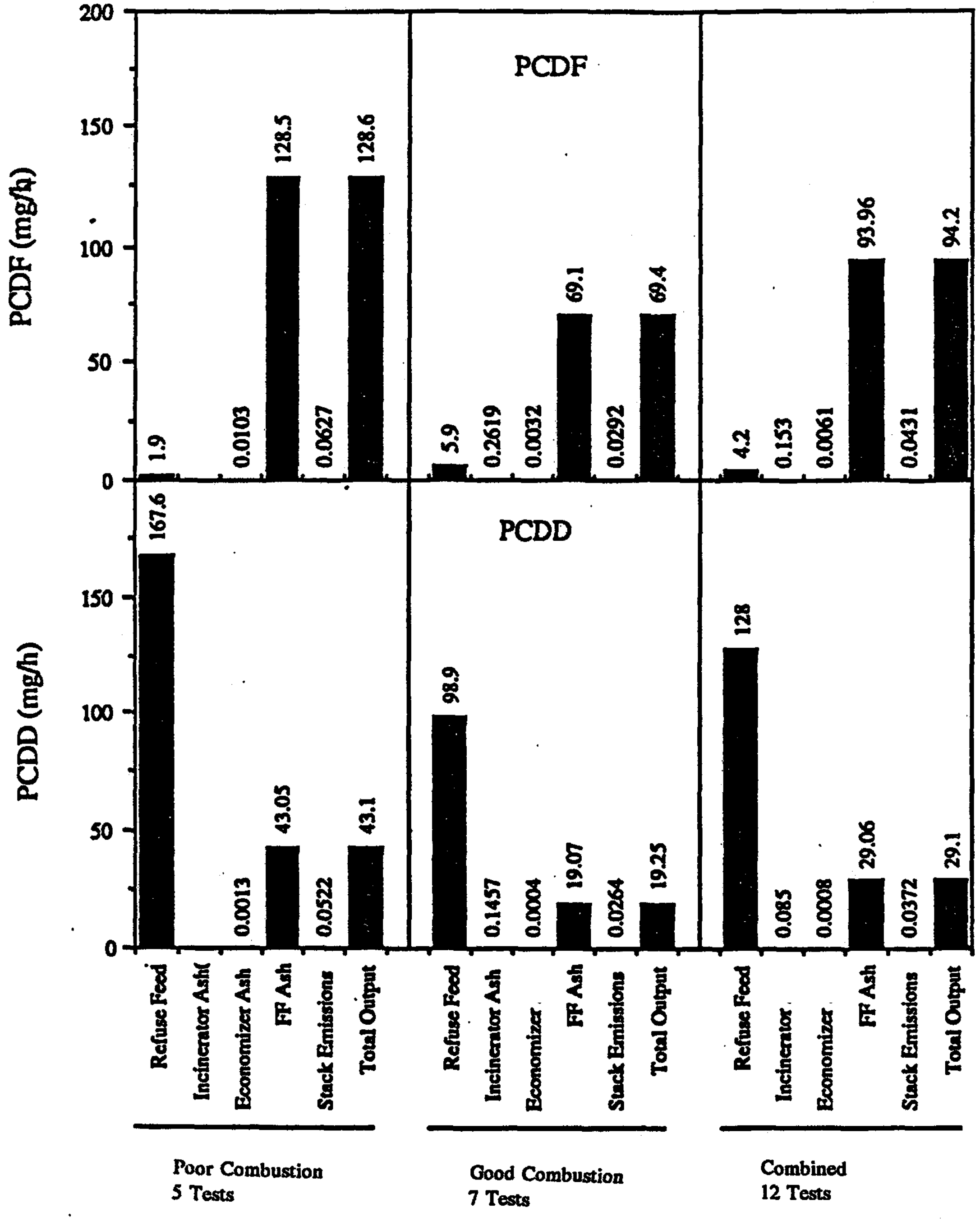


Figure 5-2. Input-Output Analysis for PCDD & PCDF

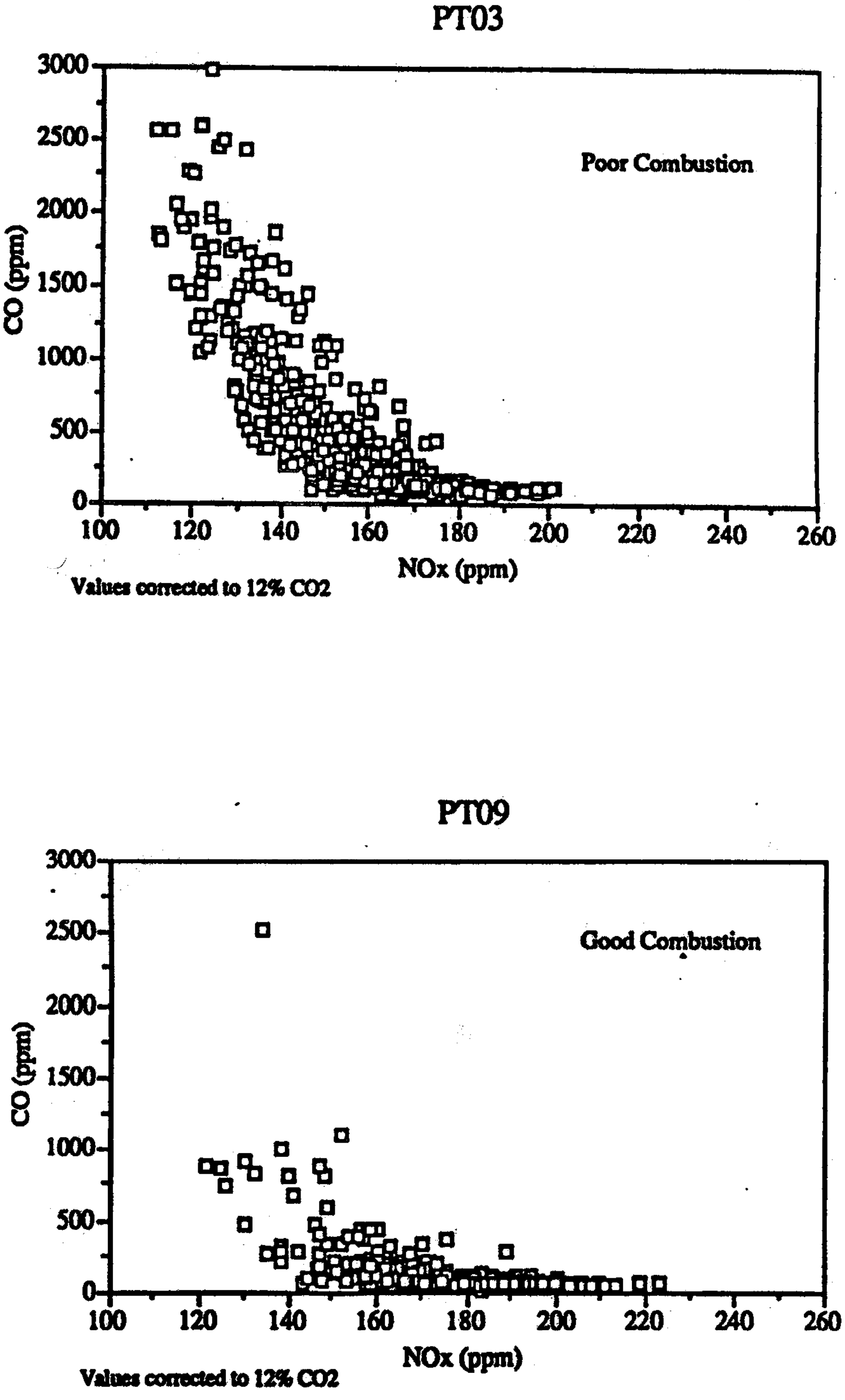
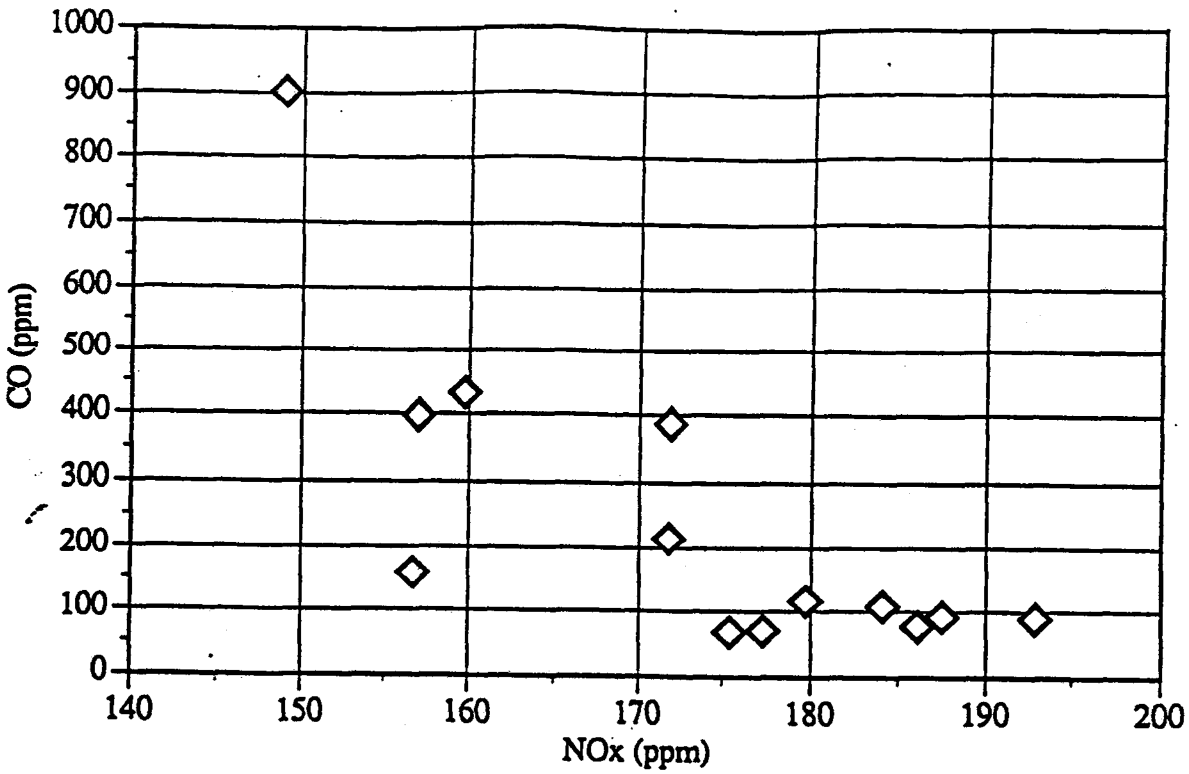


Figure 5-3. CO versus NO_x in Flue Gas at SDI



Values corrected to 12% CO_2

Figure 5-4. Test Average CO versus NO_x

NO_x. Note that the plots are not linear but hyperbolic. Therefore, a region exists at the base of the curve where moderate CO and NO_x emissions are achievable. By using a second order curve fit on the data (good combustion, normal load), a minimum average CO emission value of 71 ppm can be estimated to maintain a maximum average NO_x concentration of 180 ppm (all new MWC's over 225 Mg/day in the U.S. must comply with a NO_x limit of 180 ppm).

5.6 FURNACE FORMATION OF PCDD/PCDF

The two predominant theories regarding PCDD/PCDF formation are (1) that PCDD/PCDF is associated with the entrained particulate matter (PM) leaving the furnace, and (2) that PCDD/PCDF is formed in greater quantities during combustion upsets (or during periods of high CO emissions). The following analysis of the test data will show that during periods of good combustion a parameter indicating PCDD/PCDF formation in the furnace is the amount of entrained particulate matter exiting the furnace. For periods of poor combustion, the predominant parameter with which PCDD/PCDF formation is correlated is the level of organic matter escaping the furnace, as indicated by elevated carbon monoxide (CO) or total hydrocarbon (THC) concentrations. Accordingly, reducing PM carryover, and the frequency and magnitude of CO excursions, will result in lower PCDD/PCDF concentrations before pollution control.

5.6.1 Good Combustion - Effects of Entrained Particulate Matter

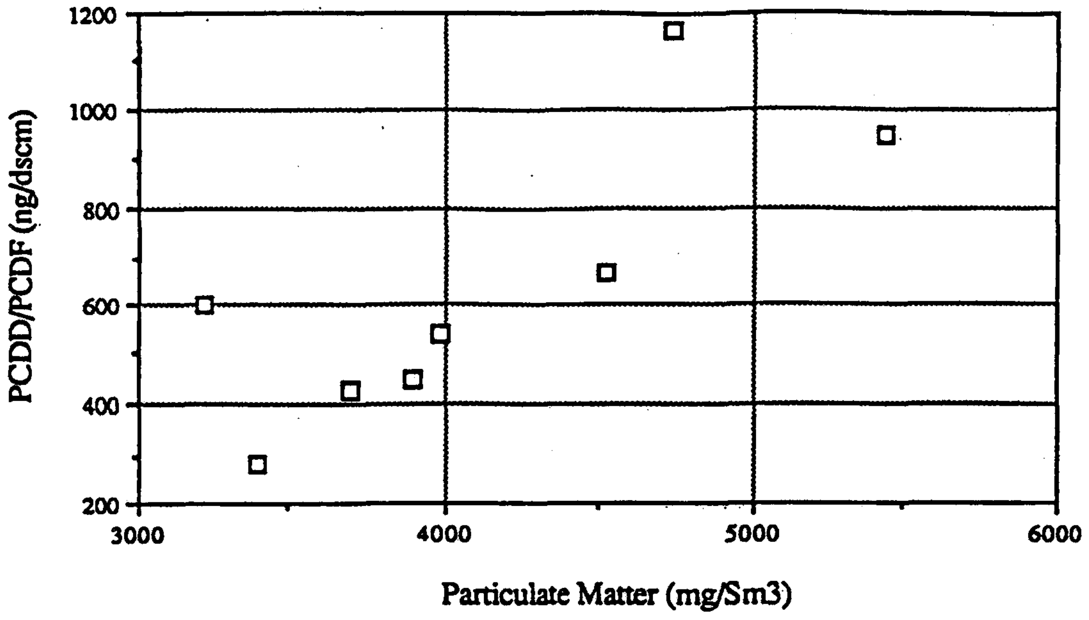
The Mid-Connecticut test program data shows a fair correlation ($R^2 = 0.61$) between entrained particulate matter and PCDD/PCDF at the spray dryer inlet for test conditions of good combustion. The relationship (illustrated in Figure 5-5) shows that PCDD/PCDF increases with increasing PM carryover. This supports the findings from other MWC test programs at Quebec City (Environment Canada, 1988) and Montgomery County (Kilgroe, 1990), and the belief that PCDD/PCDF is associated with the entrained particulate matter. One possible interpretation is that the particulate matter provides all or some of the necessary components for forming PCDD/PCDF. These components may include reaction sites (surface area), metallic promoters and organic precursor material (probably fused ring structures). Therefore, reducing PM carryover will reduce uncontrolled PCDD/PCDF emissions.

It should be noted that the relationship is significant only for good combustion. When all combustion test conditions are examined (CO > 200 ppm), the relationship is not as strong ($R^2=0.17$). The relationship for all test conditions is shown in Figure 5-6. The scatter is great. During times of poor combustion, parameters other than PM carryover provide better prediction of the concentration of PCDD/PCDF leaving the combustor, as discussed below.

5.6.2 Poor Combustion - Effects of CO Emissions

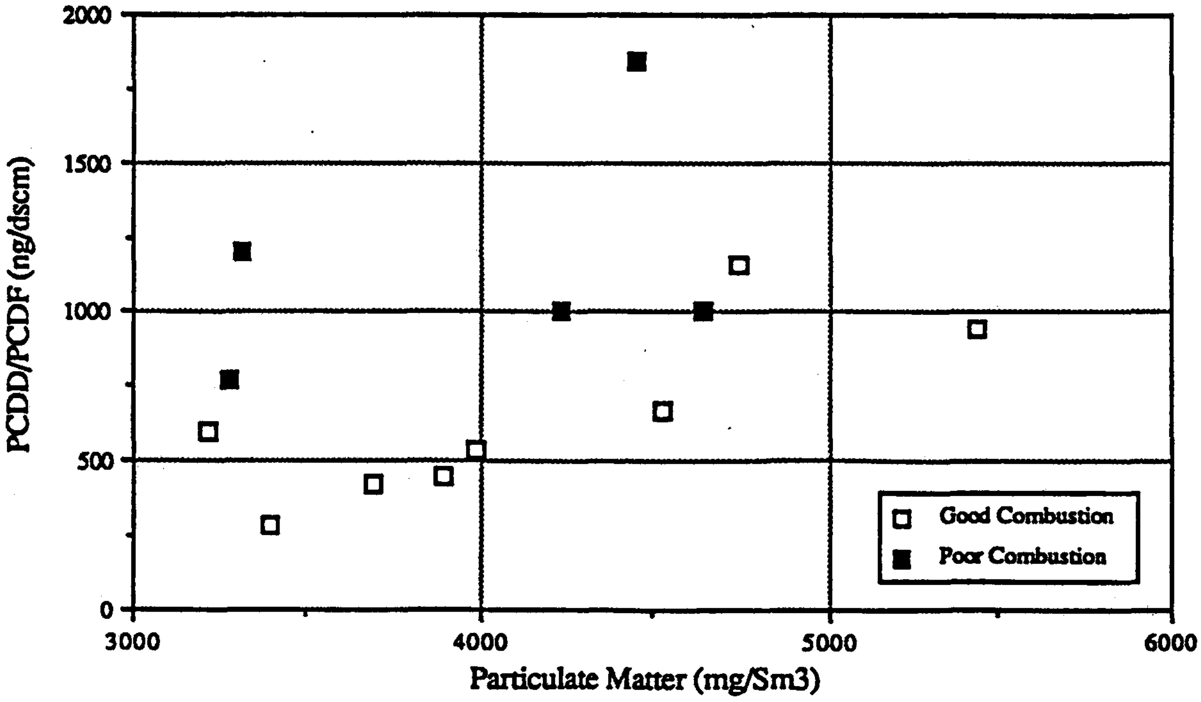
The level of carbon monoxide is a direct indicator of combustion efficiency. High levels of CO imply that the flue gases were not held at a high temperature in the presence of oxygen for a sufficient time period to convert the CO to CO_2. Very high levels of CO correspond with an increase in total hydrocarbon (THC) emissions and other organics, such as volatile compounds, semi-volatile compounds, and soot. It is this organic material that is believed to be converted into PCDD/PCDF.

The theory that higher levels of organic material escaping the furnace lead to greater levels of PCDD/PCDF was first examined by plotting the average CO and THC concentration versus the PCDD/PCDF concentration. It is evident from Figures 5-7 and 5-8 that there is a strong correlation between CO, THC and PCDD/PCDF. Note that the correlation appears stronger for poor combustion tests than for good combustion tests. Poor combustion implies greater amount of organic material escapes the combustor unburned. For CO, the poor combustion tests alone would improve R^2 from 0.70 to 0.95. This can be interpreted to mean that for all tests the variation in CO emissions can be used to explain 70 percent of the variation in PCDD/PCDF from the furnace. While for the poor combustion tests, 95 percent of the change in PCDD/PCDF values can be explained by the change in CO emissions. Similarly, the correlation between THC and PCDD/PCDF improved from an R^2 value of 0.68 when considering all test runs, to 0.97 for poor combustion tests only. These correlations support the theory that during periods of poor combustion the amount of organic matter escaping the furnace strongly influences PCDD/PCDF formation.



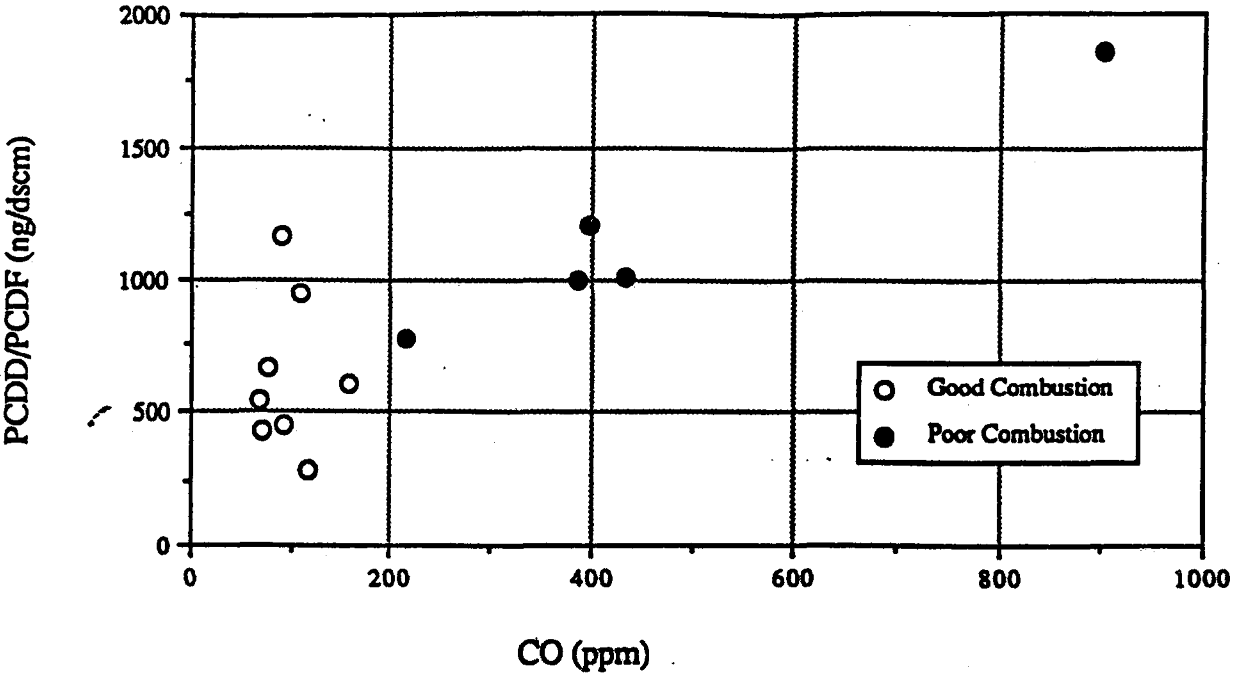
Values corrected to 12% CO2

Figure 5-5. PCDD/PCDF versus Particulate at SDI for Good Combustion Conditions



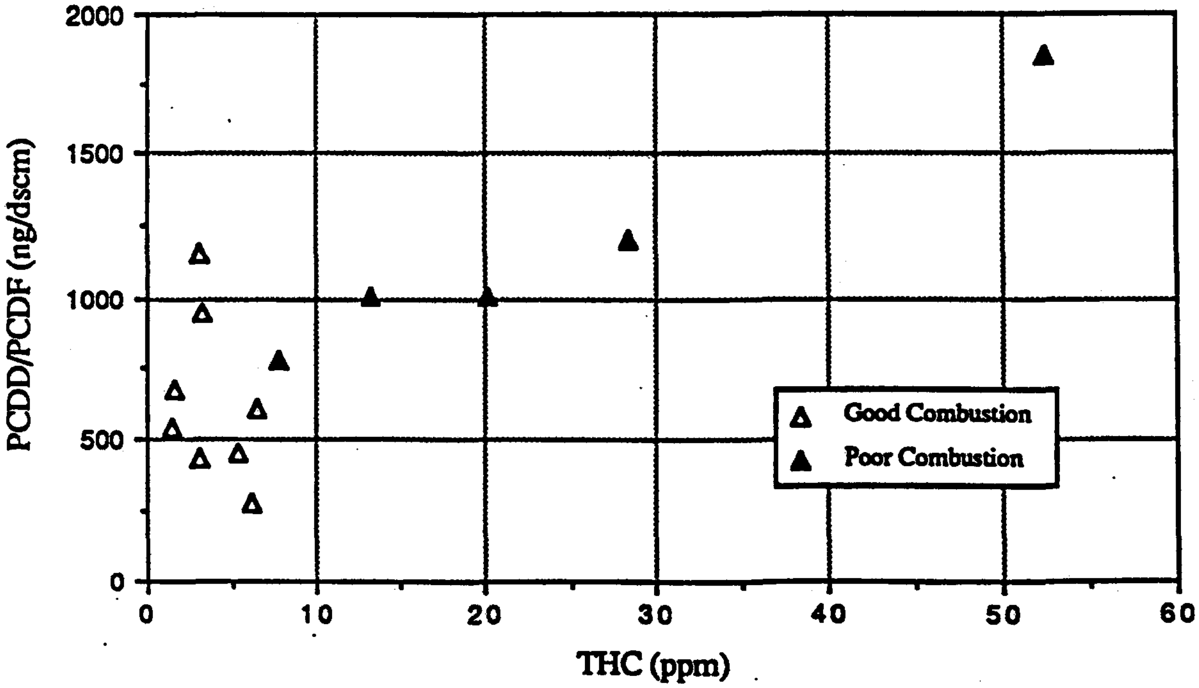
Values corrected to 12% CO2

Figure 5-6. PCDD/PCDF versus Particulate at SDI for all Tests



Values corrected to 12% CO2

Figure 5-7. PCDD/PCDF versus CO at SDI



Values corrected to 12% CO2

Figure 5-8. PCDD/PCDF versus THC at SDI

The CO and THC data generated by the continuous emission monitors can be viewed as periods of stable combustion on which short periods of unstable combustion are superimposed, where CO and THC concentrations are substantially higher. One would expect higher concentrations of PCDD/PCDF for test conditions which had many combustion excursions. One method of evaluating the possible contribution of unstable combustion conditions (CO excursions) to PCDD/PCDF emissions is to examine the percentage of operating time above a given CO concentration. The correlations between portion of time above a given CO concentration and the PCDD/PCDF concentration was examined for increments of 50 ppm and it was found that the correlations steadily improve until the portion of time that CO is greater than 400 ppm was reached, where R^2 was 0.61. Above this value, only slight improvements in the correlations were observed. A plot of PCDD/PCDF versus percent time that the CO exceeded 400 ppm is shown in Figure 5-9.

The test average CO value was a good indicator of other organic compounds besides PCDD/PCDF, such as chlorobenzene (CB), chlorophenols (CPs) and polycyclic aromatic hydrocarbons (PAHs). Uncontrolled emissions of all these organics increased with increasing CO concentration with an R^2 over 0.83. The plot of CO versus PCB showed no correlation, but this may be due to the extremely low concentrations measured (<70 ng/Sm^3).

In summary, PCDD/PCDF formation increased in the presence of greater levels of organic material as indicated by higher CO emissions. At low levels of CO (or small amounts of organic material), other factors such as particulate matter carryover probably played more important roles in determining the amount of PCDD/PCDF formed. As CO levels increased above 200 ppm, the amount of PCDD/PCDF formed increased. The formation appears to be more strongly related to absolute CO levels rather than excursions of CO above stable operation. Combustor temperature did not vary significantly and therefore it did not appear to impact organic emissions.

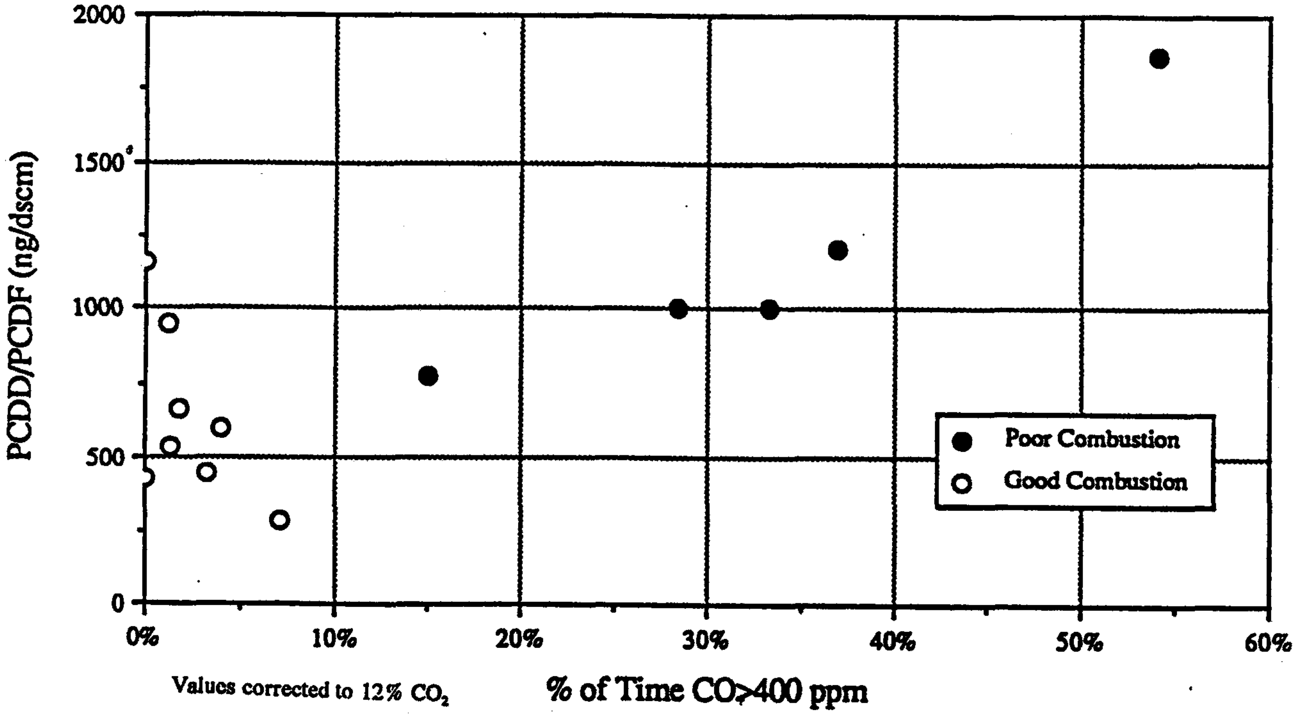


Figure 5-9. PCDD/PCDF at SDI versus Percent of Time CO > 400 ppm

5.7 PCDD/PCDF: DOWNSTREAM LOW TEMPERATURE FORMATION

Low temperature or "downstream" formation of PCDD/PCDF has been observed in many municipal waste combustors as the flue gas cools through the temperature range of 400°C to 150°C (Schindler, 1989). At the Mid-Connecticut facility, the temperature range associated with maximum net formation rates occurs in the air preheater. During the testing program, four PCDD/PCDF samples were taken at the air preheater inlet for comparison with concentrations at the SDA inlet to evaluate the formation or destruction of PCDD/PCDF as flue gas and fly ash pass through the temperature range where low temperature formation of PCDD/PCDF has been observed in other experiments. The results are shown in Figure 5-10. Contrary to expectations, a decrease across the air preheater was observed in total PCDD/PCDF for all test runs, with only PCDD showing an increase during test 10.

The observed reduction at this facility is probably related to the short time the entrained particulate matter is held in the formation temperature range. The residence time of the flue gas in the air preheater is only 1.5 to 2 seconds. The flue gases pass through the peak formation temperature (572°F) somewhere within the air preheater. This short time of less than 2 seconds may not allow significant formation of PCDD/PCDF to occur.

It may also be speculated that the observed reduction in PCDD/PCDF concentration is also due to decomposition in the duct prior to the air preheater.

Another possible explanation is artifact formation of PCDD/PCDF in sampling probe used at the air heater inlet. The flue gas temperature at the exit of the economizer averaged between 371-388°C. Therefore the gases must pass through the low temperature formation window before entering the constant temperature filters (121°C) of the sampling train. It is possible that PCDD/PCDF is formed in the probe. Thus the actual preheater inlet concentrations may be lower than the spray dryer inlet concentrations and PCDD/PCDF formation across the air heater may be occurring. Artifact formation would be expected to have a less significant impact when sampling at temperatures less than 150° C, such as at the SDI.

5.8 EFFECTS OF CARBON IN ASH ON PCDD/PCDF CONCENTRATIONS

Economizer ash hopper samples were subjected to weight loss on ignition (LOI) tests to provide information which could be used to evaluate correlations between organic material in the ash and the amount of PCDD/PCDF leaving the combustor. The relationship of economizer ash LOI to PCDD/PCDF concentration at the spray drier atomizer inlet is shown in Figure 5-11. As one would expect, the plot does show that the LOI (i.e. fraction which is carbon) is lower during good combustion tests than poor combustion test conditions. A positive correlation between PCDD/PCDF concentrations and LOI of 1 to 3-4 percent is observed. At LOI greater than 3-4 percent, the formation no longer increased. This is similar to the laboratory results of Stieglitz and Vogg (1990), which have shown that the carbon content in synthetic fly ash is proportional to PCDD/PCDF formation potential.

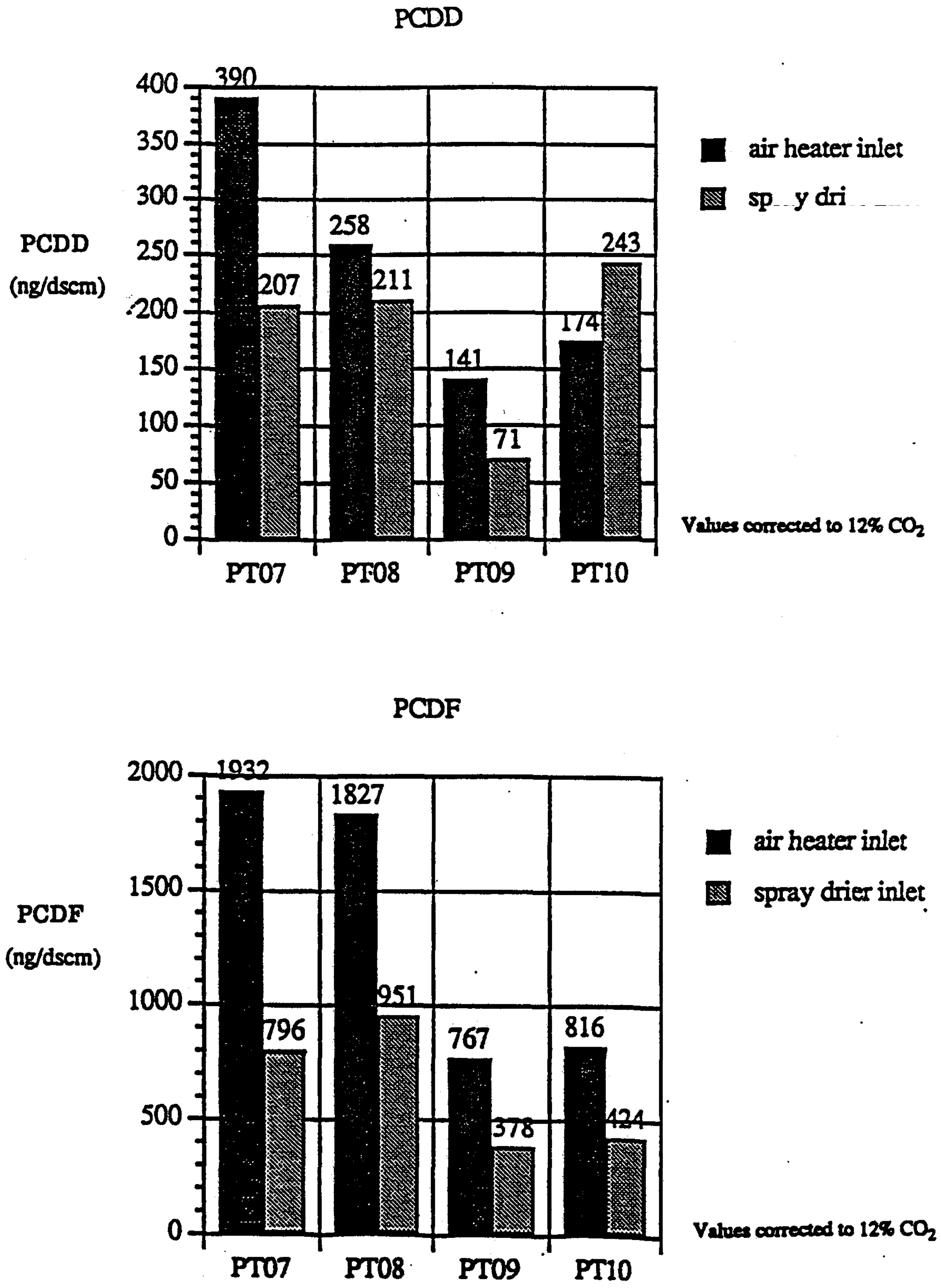
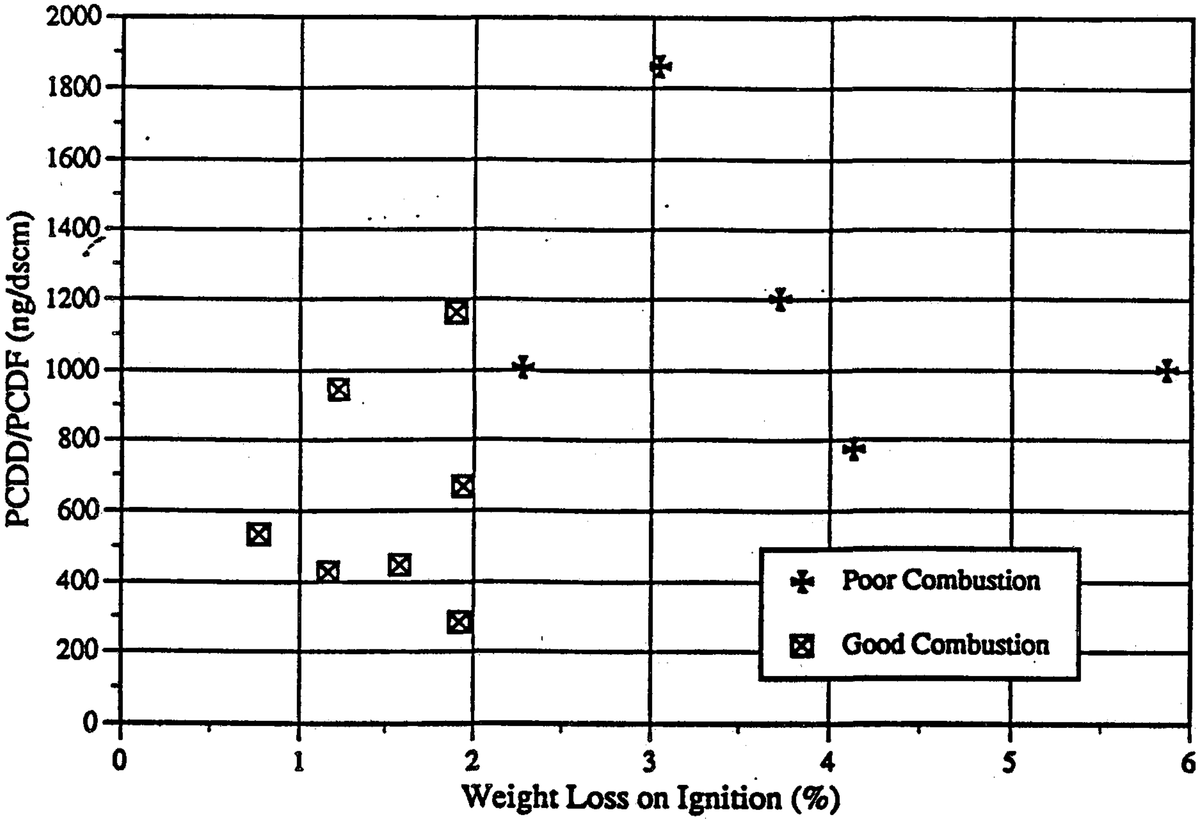


Figure 5-10. PCDD & PCDF Levels Across Air Preheater



Values corrected to 12% CO_2

Figure 5-11. PCDD/PCDF at SDI versus LOI of Economizer Ash

5.9 PARAMETERS IMPACTING CO EMISSIONS

Low CO emissions are indicative of good combustion conditions while high CO emissions correspond to poor combustion conditions. One of the overall test program objectives was to evaluate combustion system performance by determining:

- Minimum achievable CO emissions
- Operating conditions resulting in low CO emissions (<200 ppm corrected to 12% CO_2)
- Potential methods of reducing CO emissions

Average CO emissions of < 150 ppm with steady state minimum CO emissions of 30 to 50 ppm were achievable over the tested range of boiler loads. The mode of overfire air system operations which consistently produced the best mixing and performance was identified for each boiler load. CO emissions were strongly influenced by OFA system effectiveness.

Operating oxygen levels also had an impact on CO emissions. High CO emissions occurred when operating with too much or too little combustion air. This finding suggests that improving the system control and maintaining the operating O_2 level within a narrower range (less than 4% O_2 variation) would result in lower overall CO emissions.

5.10 MULTIPLE REGRESSION ANALYSIS - COMBUSTION SYSTEM

5.10.1 Overview

Statistical analysis as described in Chapter 4 is an important technique used to study the performance test data obtained. The primary goals for applying statistical analyses to the combustion system were as follows:

- To determine which emissions and operating parameters can be used as surrogate indicators for predicting trace organic emissions from the combustor; and
- To identify how various combustor operating parameters affected emissions from the combustor (prior to treatment in the APC system).

This resulted in the development of two types of models:

(a) **Prediction models** that provide a method to **predict** trace organic emissions from the combustor by **monitoring** more readily measurable parameters; and

(b) **Control models** that identify combustor operating variables which can be adjusted to **control** and **minimize** the formation and release of trace organics from the combustor.

For the combustion system, the concentration at the spray dryer inlet of each of the trace organics was selected as the dependent variable for modelling by linear regression analysis.

The independent variables were separated into two groups. Those that were used to generate **prediction models** are referred to as the "monitoring variables". Those that were used to generate the **control models** are referred to as the "control variables".

The monitoring variables for the prediction models are:

- CO
- NO_x
- H_2O
- O_2
- THC
- HCl
- SO_2
- furnace temperature
- boiler temperature
- economizer temperature
- A/H gas outlet temperature.

Some of the control variables or operational settings for the control model include:

- total undergrate air flow
- main steam flow
- rear wall air flow
- total overfire air flow
- RDF moisture

The final number of variables used in the "best fit" models was based on experience and judgement of the reviewers. In a majority of the cases, three-variable models were chosen as being adequate. In a few cases, two-variable or four-variable models were selected as the best fit.

Some of the models are illustrated in this section using graphs which show a straight diagonal line to mark the position of a perfect match between the measured values and the calculated values. Data points represented by numbers 2 to 14 correspond to the performance test runs PT-02 to PT-14. The models for each of the organics examined can be better understood by examining these graphs. The closer the numbers are to the diagonal, the stronger the model.

Two parallel lines have been placed on each side of the diagonal of these graphs: one above and one below the perfect fit diagonal. These are each displaced from the perfect fit by a distance equal to the average of the absolute values of all the residuals. The band formed by these lines is called the residual band and is used to visually represent the R^2 value. The residual band has no statistical significance beyond the purpose of visual comparisons between correlation models. The narrower the residual band, the closer the numbers approach the diagonal and, therefore, the higher the R^2 values and the better the model. As more variables are added to the model, the residual band should become narrower or else the model should be rejected. A wide residual band indicates a poor model.

The tables that accompany the figures show the progressive increase in R^2 values achieved by going from a one-variable model to a two-variable model, three-variable model and four-variable model. The best fit model is highlighted in each table.

5.10.2 Dioxin Models

The prediction model for PCDD (Table 5-12) which employed NO_x, CO and moisture in the flue gas, resulted in one of the highest R^2 values (0.89). This model, as shown in Figure 5-12, has a narrow residual band with most of the points falling within these bands.

A similar model using NO_x, CO, moisture in the flue gas and furnace temperature resulted in a higher R^2 (0.928). As discussed earlier, concentrations of PCDD before the APC are related to unburned organic material. The four variables which gave the best fit are indicators of or directly influence the completeness of the combustion process.

Unfortunately, the control models do not provide correlations which are as strong as those for the monitoring variable models. As shown in Table 5-13, maximum R^2 was 0.67. The model variables which provide the strongest correlations are combustion air flows and RDF moisture. These parameters also influence mixing and combustion completeness. It may be assumed then that some reduction in PCDD could be achieved by effective control of these parameters.

Table 5-12. Multiple Regression for PCDD at SDI Prediction Models

R^2	Variables in Model			
	CO (Corrected)	NO_x (SDI)	H_2O (SDI)	Furnace Temperature
0.79	X			
0.82	X	X		
0.89	X	X	X	
0.93	X	X	X	X

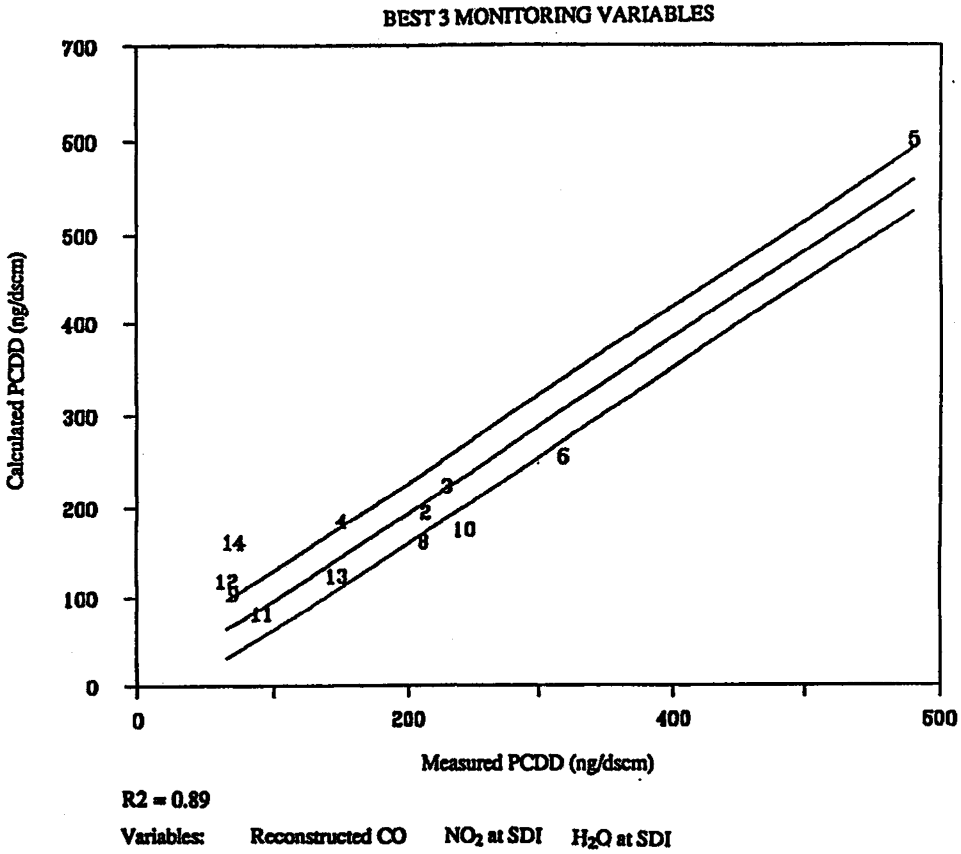


Figure 5-12. Calculated PCDD versus Measured PCDD at SDI for Prediction Model

Table 5-13. Multiple Regression for PCDD at SDI Control Models

R^2	Variables in Model			
	RDF Moisture	Rear Wall Over Fire Air	Undergrate Air Flow	Total Air
0.31	X			
0.39	X	X		
0.59	X	X	X	
0.67	X	X	X	X

5.10.3 Furan Models

The variables that produced very good predictions of PCDD concentrations at SDI also produced good predictions of PCDF at SDI. For the monitoring model with the highest R^2 (0.811), three of the four variables (CO, H_2O, and furnace temperature) are indicators of combustion conditions. The fourth variable is HCl. As discussed earlier the amount of chlorine in the refuse is believed to influence PCDD/PCDF formation. High concentration of chlorine can also suppress combustion reaction rates. Figure 5-13 shows the best three variable monitoring model for PCDF (R^2=0.78), and it uses CO, NO_x and moisture.

The control models for PCDF concentrations at SDI use the same variables as the control models for PCDD (i.e. combustion air flows and RDF moisture). Maximum R^2 was 0.67.

5.10.4 Models for Other Trace Organics

The monitoring models to predict concentrations of chlorophenols (CP), chlorobenzenes (CB) and PAH's from the combustion system (before APC) typically contained variables which are indicators of combustion performance i.e., CO, THC, or NO_x. Many of these models also contained expressions for moisture variables (RDF moisture content or flue gas moisture content) which directly or indirectly impact combustion conditions. The R^2 for the best models was typically 0.96-0.97. Further details on these prediction models are in Volume II of the report series.

The best control models for CP, CB and PAH for the most part also contain variables which are related to combustion difficulties (a high RDF moisture content) or combustion air flow distribution problems. Further evaluation of the effects of RDF moisture content and combustion air variables leads to the conclusion that organic emissions from the combustor are strongly related to combustion conditions in the lower furnace. The best control models had R^2 values of 0.83 for CP, 0.81 for CB and 0.66 for PAH. Further details are in Volume II of the report series. Good predictive or control models were not found for PCB emissions from the combustion system.

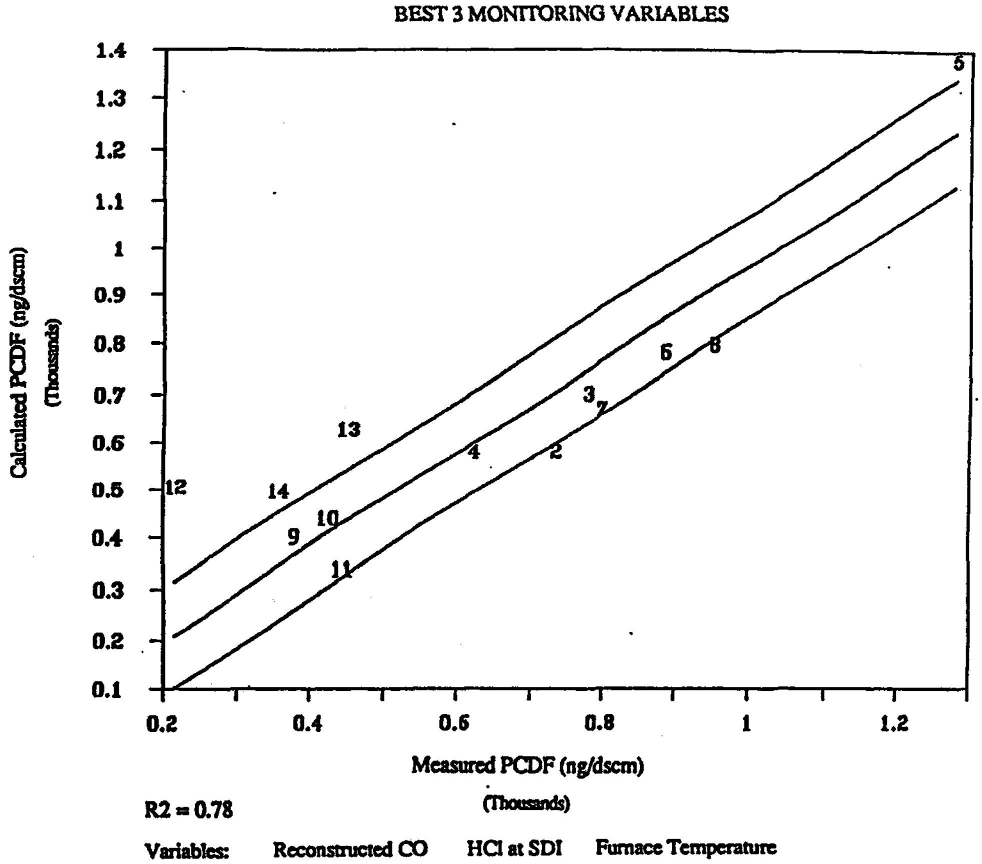


Figure 5-13. Calculated PCDF versus Measured PCDF at SDI for Prediction Model

6 PERFORMANCE TEST SERIES FOR AIR POLLUTION CONTROL SYSTEM

6.1 OVERVIEW

This section summarizes the performance test (PT) results and key findings for the air pollution control (APC) system, including concentrations at the inlet to the APC system (i.e. spray dryer inlet) and emissions from the fabric filter to the stack. The APC system test series consists of the same 13 PT runs that were discussed in Chapter 5; however, these tests have been regrouped as shown in Figure 6-1 into the nine different operating conditions of the air pollution control equipment. The data discussed in this chapter pertains only to the APC system whereas the data in Chapter 5 was relevant only to the combustion system. Concentrations at the spray dryer inlet are common to both systems and are used in both chapters.

One objective of the PT tests for the APC system was to evaluate emissions and pollutant removal efficiency at different flue gas temperatures and lime addition rates (i.e. stoichiometric ratio). SO_2 concentration at the fabric filter outlet (FFO) was used as a surrogate for stoichiometric ratio. Due to budget constraints it was not possible to run duplicate runs for each of the nine test conditions.

6.2 SUMMARY BY PERFORMANCE TEST RUN

Tables 6-1 and 6-2 summarize some of the key data generated during each PT run for the APC system. Key process data for the APC system are presented in Table 6-1, such as flue gas temperatures, pressure drops, lime slurry parameters, and flue gas flow rates. Table 6-2 presents some of the emission data at the inlet and outlet of the spray dryer and at the fabric filter outlet. Detailed test results for each PT run are presented in Volume II of the report series.

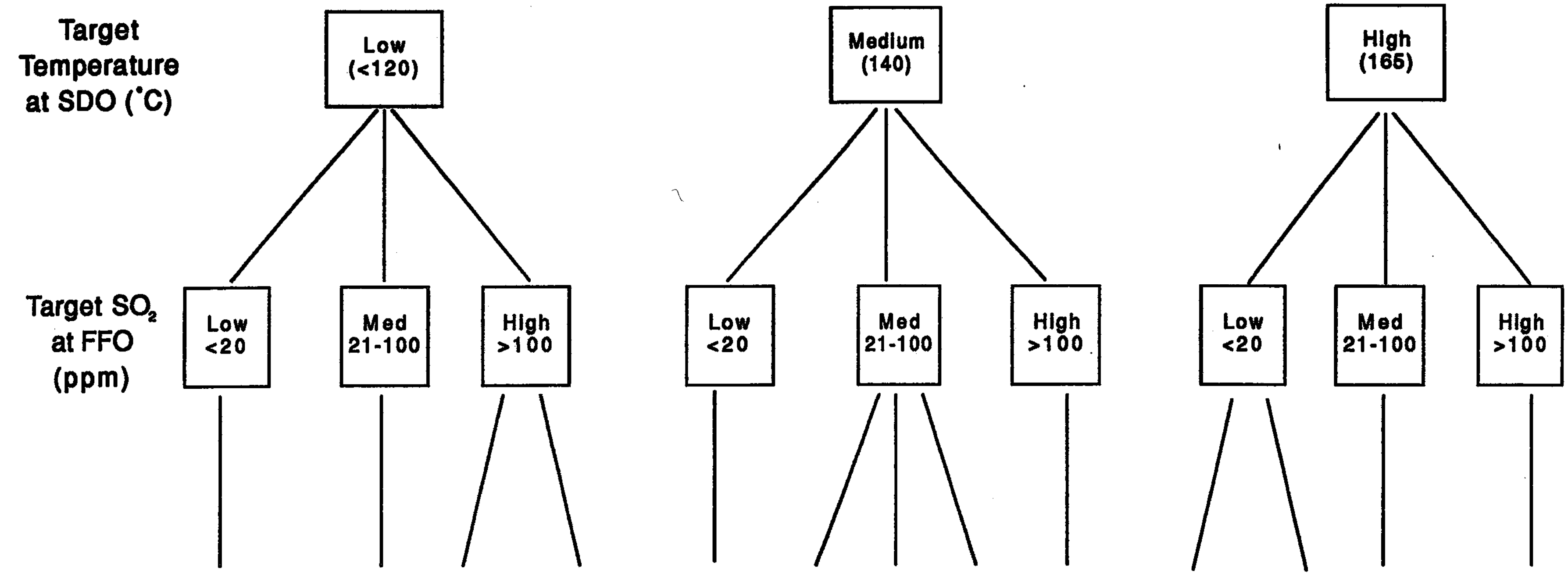
The PT runs for the APC system are categorized by flue gas temperature at the spray dryer outlet (SDO) (low, medium and high) and SO_2 concentration at FFO (which serves as a surrogate indicator of lime stoichiometry).

6.3 SUMMARY BY PERFORMANCE TEST CONDITION

Key performance test data for the APC system for each of the 9 operating conditions are shown in the 9 figures in Appendix B. These data are discussed in small segments in this Chapter.

6.3.1 APC Process Data

Table 6-3 presents key process data for the APC system, including flue gas temperature, slurry flow and SO_2 at FFO (which is an indicator of lime stoichiometry). The APC test conditions are grouped into three broad categories based on the temperature of flue gas at spray dryer absorber outlet: low (120°C), medium (140°C) and high (165-170°C). These three temperature ranges were selected to provide an indication of the effect of the degree of cooling of the flue gas (i.e. temperature at SDO) on the overall removal of pollutants by the APC system. For the low temperature category, atomizing slurry flow was highest (98-125 l/min). For the high temperature category, atomizing slurry flow was lowest (34-57 l/min) and provided less cooling of the flue gas, as desired for test purposes.



PT Number	PT7	PT10	PT2	PT5	PT6	PT12	PT13	PT14	PT8	PT3	PT11	PT4	PT9
Actual Temperature (°C) SDO	124	123	123	122	141	141	141	141	142	166	166	166	171
Actual SO_2 (ppm) at FFO	17	74	110	132	9	63	29	85	126	13	20	44	189

Figure 6-1 Performance Test Key Operating Parameters For APC System Test Series

TABLE 6-1. KEY PROCESS DATA FOR APC SYSTEM PER PT RUN

		SDO LOW TEMPERATURE				SDO MEDIUM TEMPERATURE					SDO HIGH TEMPERATURE			
SO2 AT FFO		LOW	MED	HIGH	HIGH	LOW	MED	MED	MED	HIGH	LOW	LOW	MED	HIGH
TEST #		PT-07	PT-10	PT-02	PT-05	PT-06	PT-12	PT-13	PT-14	PT-08	PT-03	PT-11	PT-04	PT-09
PROCESS TEMPERATURES														
A/H GAS OUTLET TEMP.	(°C)	204	193	192	190	185	197	179	193	203	208	187	193	193
SDA OUTLET TEMP	(°C)	124	123	123	122	141	141	141	141	142	166	166	166	171
BAGHOUSE OUTLET TEMP.	(°C)	106	106	107	104	123	119	112	119	118	139	140	142	140
OTHER APC DATA														
SDA PRESSURE DROP	(Pa)	1200	1075	1050	925	1150	1050	750	825	1100	1075	1025	1075	1025
BAGHOUSE PRESSURE DROP	(Pa)	950	975	900	900	925	975	900	900	950	975	975	950	975
ATOM. SLURRY FLOW	(l/min)	125	102	102	91	76	91	61	75	91	64	45	45	34
SLURRY FEED	(l/min)	17.0	7.2	8.7	1.9	30.0	9.5	9.5	7.9	8.3	28.0	27.0	23.0	7.2
LIME SLURRY DENSITY	(g/l)	1560	1560	1440	1500	1440	1560	1560	1560	1560	1560	1560	1560	1560
FLUE GAS FLOW RATE														
AIR HEATER INLET														
MM5 SAMPLING TRAIN:	Sm³/hr	139,000	137,000	NC	NC	NC	NC	NC	NC	131,000	NC	NC	NC	129,000
SPRAY DRYER INLET														
MM5 SAMPLING TRAIN:	Sm³/hr	158,000	154,000	151,000	146,000	160,000	143,000	132,000	141,000	149,000	148,000	145,000	153,000	145,000
METALS SAMPLING TRAIN:	Sm³/hr	158,000	156,000	155,000	148,000	162,000	145,000	123,000	137,000	151,000	147,000	148,000	156,000	148,000
FABRIC FILTER OUTLET														
MM5 SAMPLING TRAIN:	Sm³/hr	171,000	168,000	166,000	153,000	173,000	167,000	153,000	150,000	163,000	165,000	158,000	167,000	163,000
METALS SAMPLING TRAIN:	Sm³/hr	175,000	167,000	163,000	155,000	171,000	174,000	142,000	146,000	165,000	162,000	161,000	165,000	163,000

Notes: NC – Data not collected

TABLE 6-2. KEY CONCENTRATION DATA FOR APC SYSTEM PER PT RUN

SO2 AT FFO TEST #		SDO LOW TEMPERATURE				SDO MEDIUM TEMPERATURE					SDO HIGH TEMPERATURE			
		LOW	MED	HIGH	HIGH	LOW	MED	MED	MED	HIGH	LOW	LOW	MED	HIGH
		PT-07	PT-10	PT-02	PT-05	PT-06	PT-12	PT-13	PT-14	PT-08	PT-03	PT-11	PT-04	PT-09
SPRAY DRYER INLET														
* SO2	ppm	182.9	193.6	177.4	169.1	191.6	197.5	175.4	188.9	183.5	199.9	174.3	185.6	177.9
* HCl	ppm	399.4	428.6	472.3	468.7	404.4	469.5	421.4	442.3	538.2	419.0	413.3	471.3	431.5
* THC	ppm	13.3	1.6	3.3	52.4	28.6	6.1	6.4	3.0	3.0	20.1	1.5	7.7	5.4
Moisture	%	NA	13.8	13.6	15.5	14.7	16.0	12.2	12.2	16.2	17.8	15.0	14.8	17.5
PCDD	(ng/Sm^3 *)	207	243	213	580	317	67	147	72	211	230	92	151	71
	(mg/tonne **)	1.25	1.26	1.01	2.86	1.76	0.36	0.76	0.45	1.08	1.11	0.51	0.74	0.33
PCDF	(ng/Sm^3 *)	796	424	733	1281	885	215	452	356	951	778	444	623	378
	(mg/tonne **)	4.80	2.19	3.48	6.32	4.92	1.18	2.35	2.23	4.87	3.75	2.46	3.08	1.78
Mercury	(µg/Sm^3*)	584	718	726	634	583	558	531	914	646	583	661	614	644
	(g/tonne **)	3.53	3.76	3.54	3.18	3.30	3.10	2.58	5.57	3.35	2.79	3.71	3.10	3.10
Particulate	(µg/Sm^3*)	4,230,000	4,530,000	5,440,000	4,460,000	3,310,000	3,390,000	3,210,000	3,700,000	4,750,000	4,640,000	3,980,000	3,270,000	3,890,000
	(g/tonne **)	25,600	23,700	26,500	22,400	18,700	18,900	15,600	22,500	24,600	22,200	22,400	16,500	18,800
SPRAY DRYER OUTLET														
* SO2	ppm	127.3	131.4	NA	165.0	108.0	133.9	107.6	166.5	163.3	141.2	73.7	NA	158.7
* HCl	ppm	9.5	15.2	44.2	55.8	19.7	37.1	12.9	46.1	44.1	23.2	8.4	44.5	145.5
FABRIC FILTER OUTLET (STACK)														
*+ CO	ppm	387	77	108	903	397	116	158	70	89	432	68	214	92
* SO2	ppm	17.0	73.7	110.0	131.8	8.7	62.5	29.0	84.5	126.3	13.1	19.5	44.4	188.8
* HCl	ppm	7.7	18.8	20.0	20.9	10.2	16.7	18.4	20.0	40.6	17.5	23.1	30.8	98.2
* THC	ppm	12.4	1.9	1.4	35.3	26.1	5.4	1.8	NA	1.6	14.9	2.3	5.1	8.5
PCDD	(ng/Sm^3 *)	0.167	0.181	0.079	0.371	0.346	0.067	0.108	0.012	0.286	0.562	0.131	0.368	0.582
	(µg/tonne**)	0.93	0.89	0.37	1.68	1.86	0.36	0.57	0.07	1.41	2.71	0.69	1.83	2.71
PCDF	(ng/Sm^3 *)	0.145	0.103	0.121	1.124	0.162	0.075	0.269	0.020	0.467	0.376	0.194	0.486	0.495
	(µg/tonne**)	0.81	0.50	0.56	5.09	0.87	0.41	1.42	0.12	2.30	1.81	1.02	2.43	2.30
VOST	(ng/Sm^3 *)	984,000	151,000	53,500	3,370,000	175,000	685,000	100,000	56,200	253,000	606,000	59,800	307,000	416,000
	(µg/tonne**)	5,580	735	247	15,300	929	3,820	512	325	1,260	2,900	316	1,520	1,930
Mercury	(µg/Sm^3*)	7.4	8.4	6.5	6.8	11.5	3.2	11.0	13.4	4.2	21.4	17.8	13.4	14.1
	(g/tonne **)	0.042	0.041	0.030	0.031	0.061	0.018	0.054	0.076	0.021	0.102	0.095	0.066	0.066
Particulate	(µg/Sm^3*)	4,390	4,090	5,770	3,880	2,680	3,980	7,690	4,720	3,880	5,500	5,700	7,620	5,790
	(g/tonne **)	25.2	19.9	26.4	17.8	14.2	22.7	37.9	26.9	19.4	26.1	30.4	37.6	26.9

NA = not available
* – Corrected to 12% CO2
** – Refuse as fired
\+ – Reconstructed from measurements at SD inlet and FF outlet.

Table 6-3. Key Process Data for APC System per Performance Test Condition

	SDO Low Temp (120°C)			SDO Medium Temp (190°C)			SDO High Temp (165°C)		
SO_2 at FFO - Target	Low	Med	High	Low	Med	High	Low	Med	High
- Actual (ppm)	17	74	121	9	59	126	17	44	189
Test Number	7	10	2, 5	6	12,13,14	8	3,11	4	9
A/H Outlet Temp (°C)	204	193	191	185	190	203	198	190	193
SDA Outlet Temp (°C)	124	123	122	141	140	142	165	166	170
Baghouse Outlet Temp (°C)	106	106	106	123	117	118	140	142	140
SDA Pressure Drop (Pa)	1200	1075	1000	1200	875	1100	1050	1075	1025
Baghouse Pressure Drop (Pa)	950	975	900	925	950	950	975	950	975
Atomizer Slurry flow (l/min)	125	120	98	76	76	91	57	45	34
Slurry Feed (l/min)	17	7.2	5.3	30	9	8.3	28	23	7.2

Within each of the temperature categories, the amount of lime was allowed to vary from very low to medium to a high amount (which is indicated by high SO_2 (over 100 ppm), medium SO_2 (21-100 ppm), and low SO_2 concentrations (under 20 ppm) at the fabric filter outlet). Since lime stoichiometric ratio was not readily known, SO_2 concentration at FFO was used as a surrogate, which immediately indicated that there was more or less lime used.

6.3.2 CEM Data

The CEM data for SO_2, HCl and THC are summarized in Table 6-4 for each PT condition of the APC system and includes CEM data at spray dryer inlet (SDI), spray dryer outlet (SDO), and fabric filter outlet (FFO).

SO_2 concentrations at the spray dryer inlet (i.e. from combustor) ranged from 170 to 200 ppm, which is typical for MSW incinerators. SO_2 was between 100 and 160 ppm at the SDO and between 9 and 190 ppm at the FFO, depending on the flue gas temperature and the amount of lime used. SO_2 removal efficiency is illustrated in Figure 6-2. Clearly, SO_2 removal by the APC system can be easily controlled and can range from good removal (over 90% and <20 ppm at stack) to poor removal (under 20% and >100 ppm at stack), depending on operating conditions selected for the spray dryer and fabric filter. As shown in Figure 6-2, up to 60% of SO_2 removal occurs across the spray dryer, the balance occurring across the fabric filter.

HCl concentrations at the SDI (i.e. from combustor) ranged from 400 to 540 ppm, which is typical for MSW incinerators. HCl was between 10 to 50 ppm at the SDO for all PT conditions (except PT9 at 146 ppm) and 8 to 40 ppm at the FFO for all PT conditions (except PT9 at 98 ppm). HCl removal efficiency is illustrated in Figure 6-3. It is clear that HCl removal over 95% and stack emissions below 20 ppm are possible, depending on the operating conditions selected for the spray dryer and fabric filter. Because of its high reactivity, HCl removal exceeded 92%, even when there was low SO_2 removal of 20%. Most of the HCl removal occurred across the spray dryer; the fabric filter accounted for less than 10% removal of the total HCl. A more detailed discussion of operating variables for SO_2 and HCl removal is provided in Section 6.4.

Table 6-4. CEM Data for APC System per Performance Test Condition

	SDO Low Temp (120°C)			SDO Medium Temp (140°C)			SDO High Temp (165°C)		
SO_2 at FFO - Target	Low	Med	High	Low	Med	High	Low	Med	High
Test Number	7	10	2, 5	6	12,13,14	8	3,11	4	9
<u>Spray Dryer Inlet</u> (ppm at 12% CO_2)									
- SO_2	183	194	173	192	187	184	187	186	178
- HCl	399	429	470	404	445	538	416	471	432
- THC	13	2	29	29	5	3	11	8	5
<u>Spray Dryer Outlet</u> (ppm at 12% CO_2)									
- SO_2	127	131	NA	108	136	163	107	NA	159
- HCl	10	15	50	20	32	44	15	45	146
<u>Fabric Filter Outlet</u> (ppm at 12% CO_2)									
- SO_2	17	74	121	9	59	126	17	44	189
- HCl	8	19	20	10	18	41	21	31	98
- THC	12	2	19	26	3	2	9	5	9

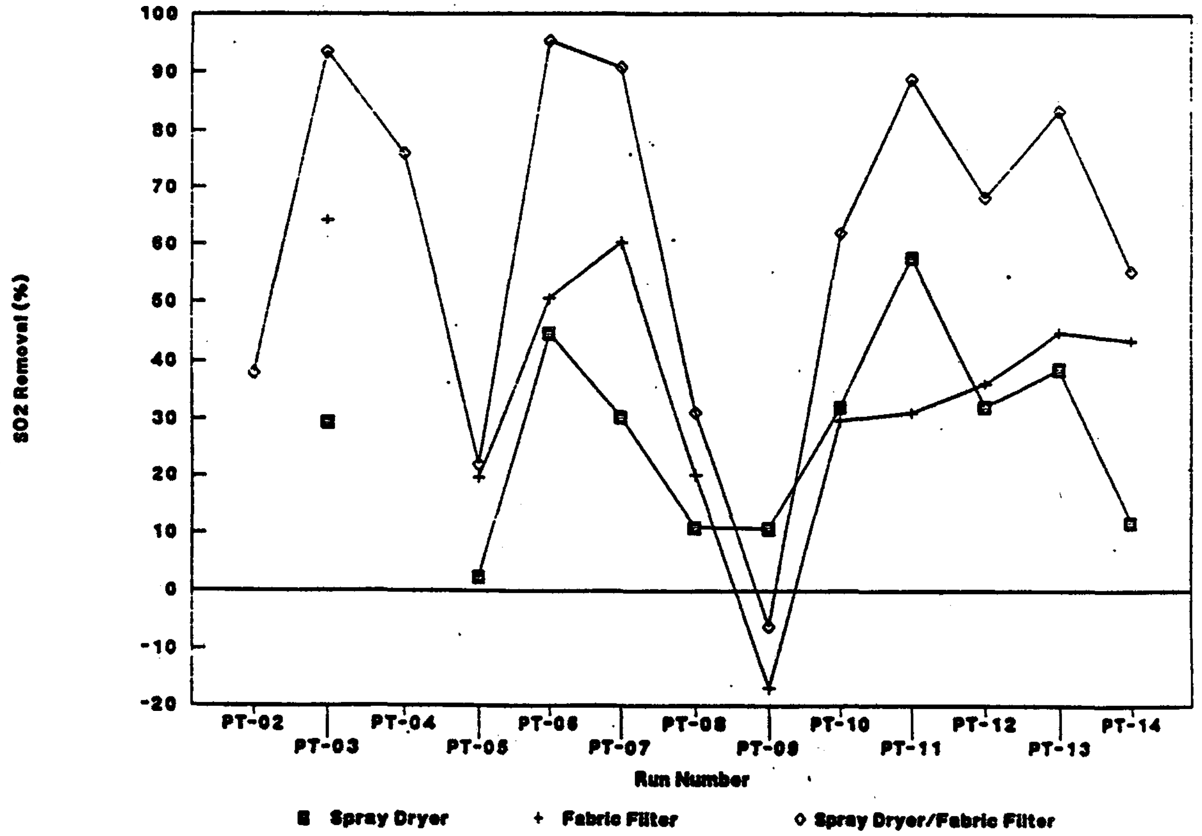


Figure 6-2. SO_2 Removal Efficiency per PT Run

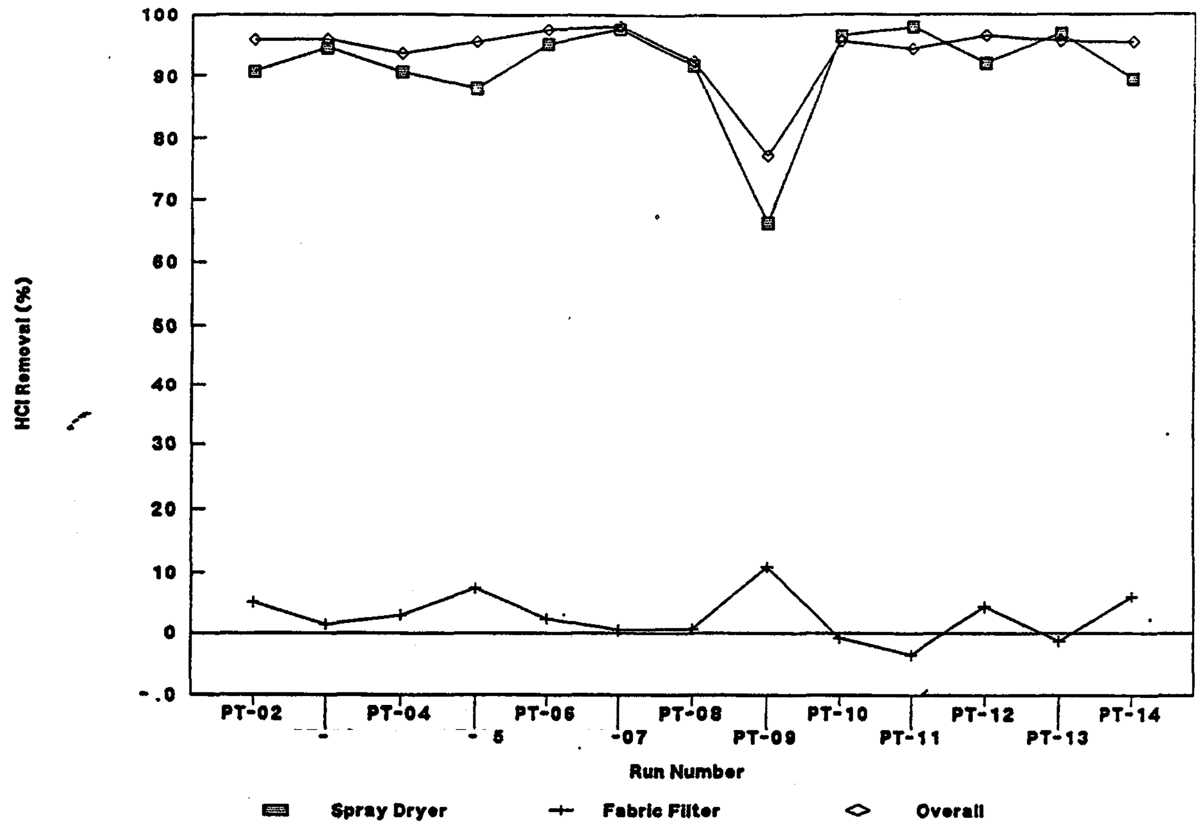


Figure 6-3. HCl Removal Efficiency per PT Run

6.3.3 Trace Organic Concentrations

Trace organic concentrations at the SDI (i.e. from combustor to APC system) and at FFO (i.e. after APC system) are summarized in Table 6-5 for the different PT conditions of the APC system.

PCDD was reduced from a range of 70-400 ng/Sm^3 to less than 0.6 ng/m^3. This is a PCDD removal efficiency of more than 99.7% in all cases (except for PT9 at 99.2%).

PCDF was reduced from a range of 300-1000 ng/Sm^3 to less than 0.6 ng/Sm^3 in all cases, except PT5 at 1.1 ng/Sm^3. The removal efficiency for PCDF exceeded 99.9% for all test runs.

In summary PCDD/PCDF removal was consistently high for all test runs and APC operating conditions. Because PCDD/PCDF removal was so high, it is difficult to distinguish whether process operating parameters had any significant effect on removal efficiency or whether differences in removal efficiency are due to limits in sampling and analytical precision. Statistical analysis for correlations and multiple regression analysis indicated that APC operating conditions appeared to have little, if any, effect on PCDD/PCDF control. HCl concentration at FFO, FF pressure drop, and SD outlet temperature appeared to have a weak impact on PCDD removal. As each of these parameters increased, PCDD removal decreased slightly. Note, however, that PCDD removal was over 99.2 percent in all cases.

The data in Table 6-5 for CB, CP and PAH concentrations are further summarized as follows:

	Spray Dryer Inlet (ng/Sm^3)	Fabric Filter Outlet (ng/Sm^3)
CB	5,000-11,000	100-500
CP	11,000-63,000	100-1,600
PAH	6,000-90,000	2,000-5,000

There is a wide variation in concentration at the spray dryer inlet. As discussed in Chapter 5 above, the higher values occurred under poor operating conditions of the combustor system. The significant reduction in CB, CP and PAH concentrations across the APC system is apparent in the above data. Removal efficiency of CB, CP and PAH by the APC system was significant: over 94% for CB and CP and over 60% for PAH.

PCB concentrations at both locations were relatively low, under 40 ng/Sm^3. PCB was not detected at the fabric filter outlet (i.e. the stack) for almost all operating conditions, except where spray dryer outlet temperature was relatively high (i.e. 165°C).

Table 6-5. Trace Organics Concentrations for APC System Per Performance Test Condition

	SDO Low Temp (120°C)			SDO Medium Temp (140°C)			SDO High Temp (165°)		
SO_2 at FFO - Target	Low	Med	High	Low	Med	High	Low	Med	High
Test Number	7	10	2, 5	6	12,13,14	8	3,11	4	9
<u>Spray Dryer Inlet</u>									
(ng/Sm^3 @ 12% CO_2)									
- PCDD	207	243	396	317	95	211	161	151	71
- PCDF	796	424	1,007	885	341	951	611	623	378
- PCB	17	13	23	12	ND	24	42	ND	6
- CB	7,100	6,200	10,900	9,400	4,600	7,100	6,200	6,000	4,800
- CP	25,200	16,200	62,900	41,600	14,400	20,200	20,800	17,000	11,300
- PAH	51,800	6,300	60,200	88,600	7,700	10,300	47,100	22,500	32,400
<u>Fabric Filter Outlet</u>									
(ng/Sm^3 @ 12% CO_2)									
- PCDD	0.17	0.18	0.23	0.35	0.06	0.29	0.35	0.37	0.58
- PCDF	0.15	1.10	0.62	0.16	0.12	0.47	0.29	0.49	0.50
- PCB	ND	ND	ND	ND	ND	7	27	19	14
- CB	110	42	400	540	ND	110	290	90	110
- CP	230	80	1,600	1,300	90	190	190	170	390
- PAH	1,400	2,600	4,800	2,000	2,900	2,400	3,700	2,000	2,400

6.3.4 Particulate/Metal Concentrations

The range of particulate and trace metal concentrations is summarized in Table 6-6, for the SDI and the FFO.

Particulate concentrations were reduced very significantly from a range of 3,210-5,440 mg/Sm^3 at the SDI to 3-8 mg/Sm^3 at the FFO. This corresponds to a particulate removal efficiency that exceeds 99.7%. This is consistent with the good performance expected for the fabric filter dust collector (i.e. emissions below 10 mg/Sm^3).

Trace metals were also significantly removed by the APC system, typically from thousands (μg/Sm^3) to less than 90 μg/Sm^3. Several metals (eg. As,Sb, Cd and Zn) showed non-detectable concentrations at the FFO. Accordingly, trace metal removal was very high, including Hg removal (over 96% for all test runs) except for Ni in run PT8 (84%). There is no obvious explanation for the lower removal efficiency of Ni for PT8.

Due to the high removal efficiencies for particulate and metals, it is difficult to determine whether any differences in emissions or removal efficiency were due to process operating conditions or limitations in sampling/analytical precision. The removal of Hg was investigated further, as discussed below in Section 6.4.

Table 6-6. Particulate and Trace Metal Range of Concentrations

	Spray Dryer Inlet	Fabric Filter Outlet
Particulate mg/Sm^3	3,210-5,440	2.7-7.7
Trace Metals μg/Sm^3		
- Mercury	531-914	7-21
- Antimony	44-173	ND
- Arsenic	159-270	ND
- Cadmium	437-832	ND
- Chromium	353-1,095	8-32
- Copper	1,100-3,220	ND
- Lead	2,600-14,700	29-91
- Nickel	257-2,230	2-67
- Zinc	31,000-50,000	ND

6.4 MULTIPLE REGRESSION ANALYSIS - APC SYSTEM

The statistical analysis techniques described in Sections 4.7 and 5.10 for the combustion system were also applied to the APC system. In particular, the process operating variables for the APC system that may affect acid gas removal (HCl and SO_2) and mercury removal are discussed in this report section. The removal of other pollutants was also examined for relevant correlations, but no statistically significant relationships were found.

6.4.1 APC Operating Variables for Regression Analysis

One objective of the program was to determine the impact of APC system operating parameters on removal of acid gas and mercury.

The two process parameters generally having the greatest impact for acid gas control by lime spray dryer/fabric filters systems are the approach to adiabatic saturation temperature of the flue gas and the stoichiometric ratio of available alkali to acid gases.

The adiabatic approach to saturation temperature is a function of the flue gas temperature and moisture content, and provides an indication of the length of time wetted alkali remains reactive. As the flue gas temperature approaches the adiabatic saturation temperature, the reactivity of the sorbent decreases. Because of problems with directly monitoring adiabatic saturation temperature, however, the flue gas temperature at the SD or FF outlet was used for process control.

The stoichiometric alkali-to-acid gas ratio is a function of the total content of reactive alkali in added sorbent, fly ash, slaking, and slurry dilution water and the concentration of individual acid gases in the flue gas.

Due to limitations in determining the total alkali input to the spray dryer, calculation of stoichiometric sorbent feed rates were based on the alkalinity in the lime slurry alone. To help interpret SD/FF performance, two different stoichiometric ratio formulas were used. The first formula, referred to as the overall stoichiometric ratio (OSR), is the commonly used format for comparing moles of alkali to moles of acid gases:

$$\text{OSR} = \frac{\text{moles/hr of } Ca(OH)_2}{\text{moles/hr of } SO_2 + \tfrac{1}{2}(\text{moles/hr of HCl})}$$

The second formula, referred to as the reduced stoichiometric ratio (RSR), recognizes that HCl is more reactive than SO_2, and that the amount of alkali available for reaction with SO_2 is a function of the amount of alkali remaining after reaction with HCl. Assuming 100 percent reaction of HCl with the alkali, RSR is defined as:

$$\text{RSR} = \frac{\text{moles/hr of } Ca(OH)_2 - \tfrac{1}{2}(\text{moles/hr of HCl})}{\text{moles/hr of } SO_2}$$

6.4.2 Correlations for SO_2 Removal

The SO_2 removal efficiency of the APC system is shown as a function of the Overall Stoichiometric Ratio (OSR) in Figure 6-4. A similar relationship was obtained for SO_2 removal versus Reduced Stoichiometric Ratio (RSR). There is a relevant dependence of SO_2 removal by the APC system on stoichiometric ratio.

The SO_2 removal is plotted versus OSR for the three flue gas temperatures in Figure 6-4. The scatter of the points is such that the effect of flue gas temperature on SO_2 removal appears to be very weak for any selected SR value. However, multivariate analysis, as discussed next, does indicate that flue gas temperature has some effect on SO_2 removal by the APC system.

Based on multivariate analysis, a strong relationship ($R^2 = 0.90$) was found to predict SO_2 removal by the APC system versus overall SR and flue gas temperature at FFO. The statistical relationship is expressed as follows:

$$\ln(100 - \text{overall \% } SO_2 \text{ Removal}) = -1.3986\,(\text{OSR}) + 0.0177\,(\text{FFO Temperature}) + 0.6087$$

The performance of this prediction model using OSR and FFO temperature is illustrated in Figure 6.5, where the calculated values of SO_2 removal are plotted against the measured values of SO_2 removal.

Correlations of SO_2 removal across the spray dryer versus SR and SO_2 removal across the fabric filter versus SR were also completed and show a strong relationship between % removal and SR, as expected.

To examine the effect on SO_2 removal of HCl in the flue gas, SO_2 removal by the spray dryer versus HCl at SDI was plotted in Figure 6-6. This figure suggests that HCl levels may influence the SO_2 removal efficiency across the SD. Since HCl is more reactive with lime than is SO_2, the sorbent available for reaction with SO_2 depends on the HCl concentration for a given SR. Therefore, at higher HCl concentrations for a given SR, SO_2 removal will be lower. A similar relationship was found for SO_2 removal across the fabric filter versus HCl at SDO.

Various other statistical relationships developed from multivariate analyses for SO_2 removal are discussed in Volume II of the report series.

6.4.3 Correlations for HCl Removal

The HCl removal efficiency of the APC system is shown in Figure 6-7 as a function of the Overall Stoichoimetric Ratio (OSR). The effect of SR on HCl removal appears to be rather small for the range tested. Flue gas temperature appears to affect HCl removal, as can be seen from lower HCl removal for the PT runs at 168°C versus 140°C or 124°C (i.e. points ◇ versus points ☐ or +). These relationships were further investigated by a multivariate analysis.

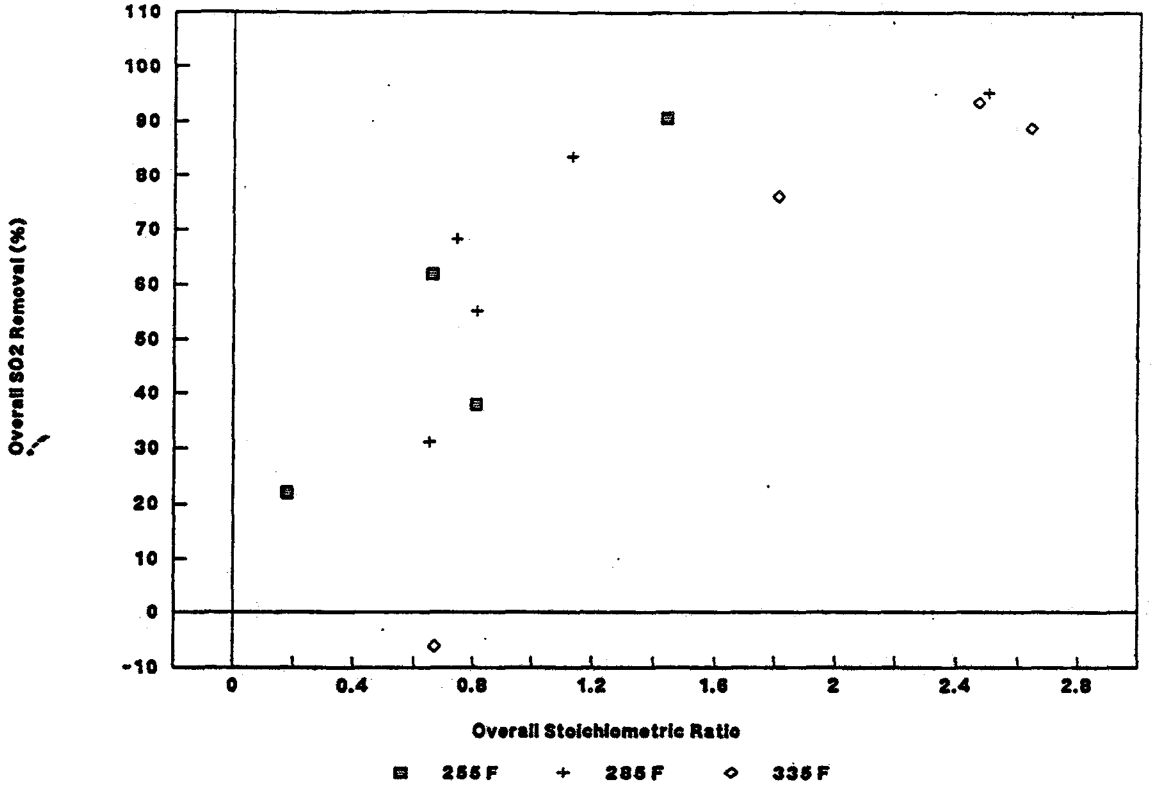


Figure 6-4. SO_2 Removal by APC System versus Overall Stoichiometric Ratio (OSR) One Variable Model (OSR)

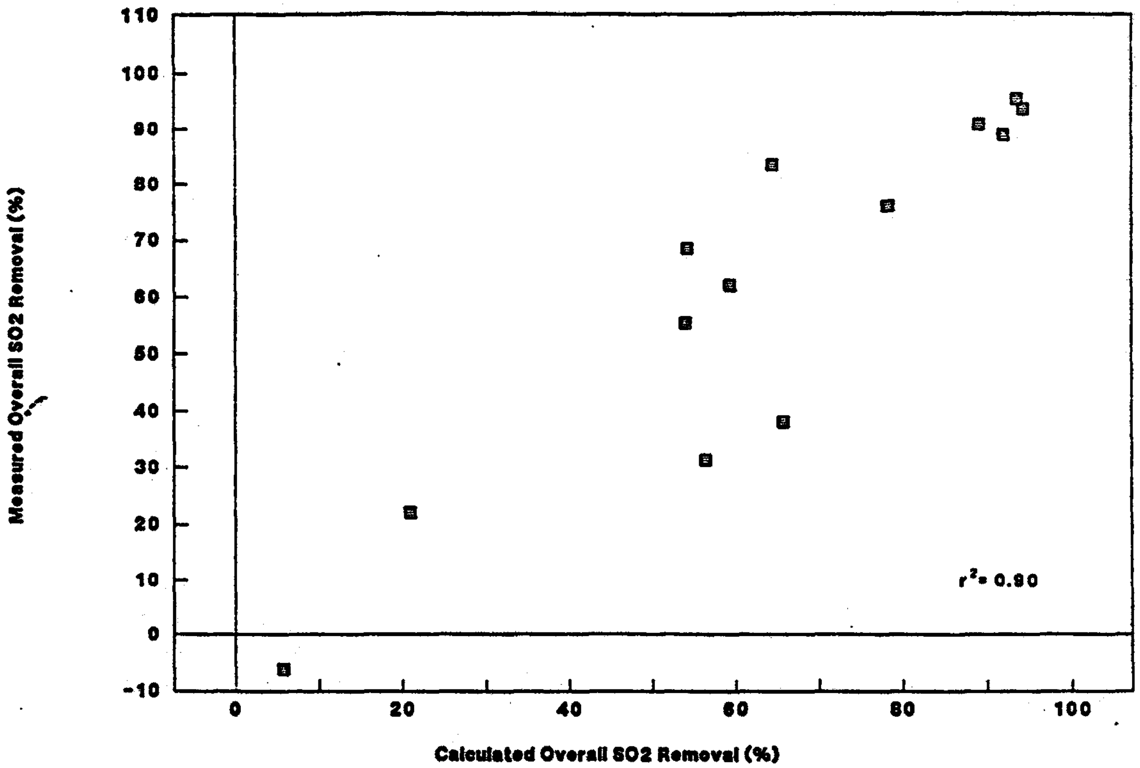


Figure 6-5. Measured versus Calculated Overall SO_2 Removal, Two Variable Model (OSR and FFO Temperature)

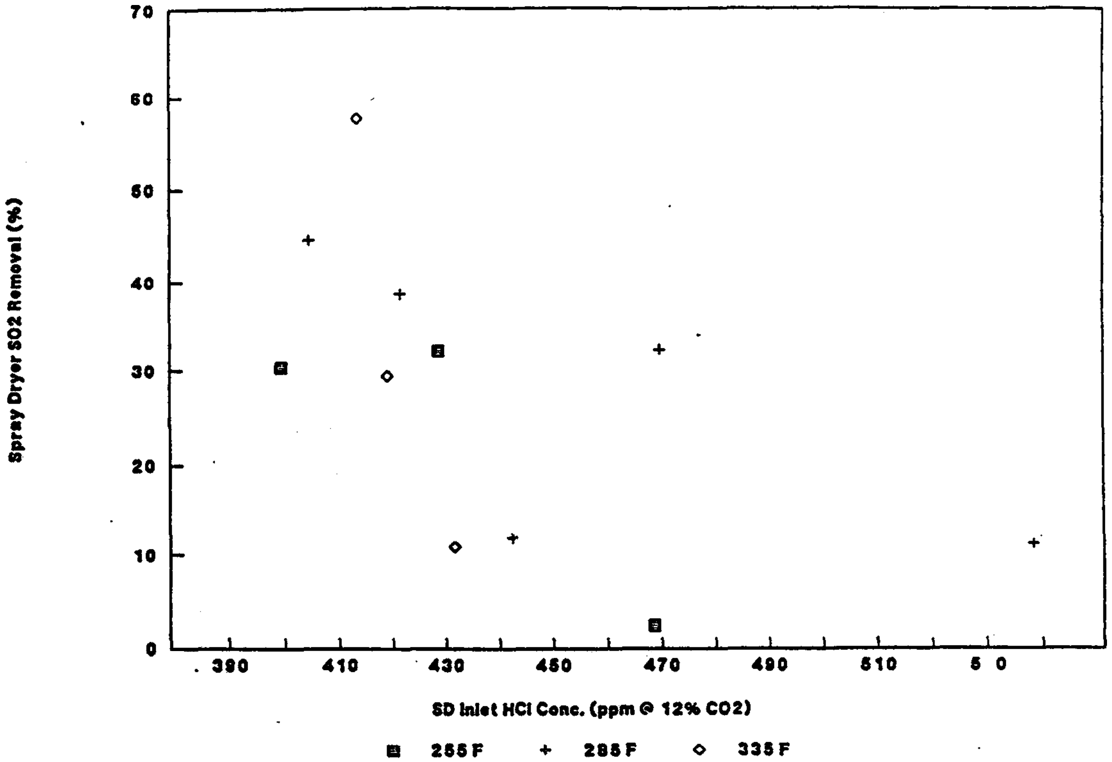


Figure 6-6. SO_2 Removal by Spray Dryer versus HCl at SDI

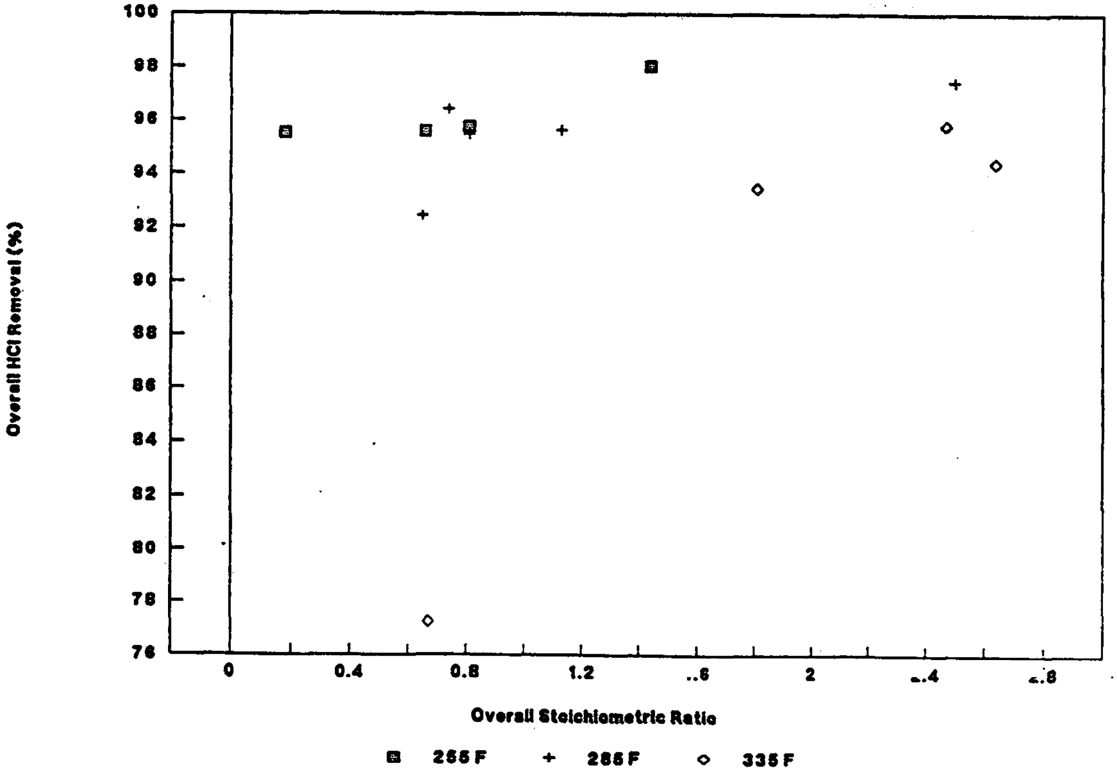


Figure 6-7. Overall HCl Removal by APC System Versus Overall Stoichiometric Ratio

Based on multivariate analysis, a good relationship ($R^2 = 0.82$) was found for HCl removal by the APC system using the two variables of SR and flue gas temperature at SDO. The statistical relationship is expressed as follows:

$$\ln(100 - \text{Overall \% HCl Removal}) = -0.270\,(\text{RSR}) + 0.0186\,(\text{SDO Temperature}) - 3.4111$$

This relationship is illustrated in Figure 6-8. Other statistical relationships for % HCl removal are discussed in Volume II of the report series.

6.4.4 Correlations for Trace Organics Removal

As indicated above in Section 6.3, APC operating conditions appeared to have little, if any, effect on the removal of PCDD/PCDF by the APC system for the range tested. Based on statistical analyses, HCl at FFO, FF pressure drop and SDO temperature appeared to decrease PCDD removal slightly ($R^2 = 0.71$), when any of these parameters increased in value.

6.4.5 Correlation for Hg Removal

The removal of mercury by APC systems for municipal waste combustors has become an important issue to the industry. Some facilities have reported good mercury removal, whereas others have measured poor mercury removal. Accordingly, the PT data were analyzed statistically to identify parameters that may be relevant for good mercury removal.

The operating parameters selected for analyses for mercury removal efficiency of the APC system were flue gas temperature, stoichiometric ratio, FF pressure drop and % carbon in FF ash (based on % LOI).

Figure 6-9 shows OSR versus mercury removal efficiency across the SD/FF system. The figure indicates that mercury removal decreased as OSR increased. This phenomenon suggests that chlorine may be stripped from $HgCl_2$ formed in the flue gas at higher stoichiometric ratios. As a result, volatile ionic Hg^{2+} may be liberated, resulting in increased mercury emissions. Because acid gas removal increases with increasing stoichiometric ratio, a tradeoff may exist between acid gas and mercury control levels.

Figure 6-10 illustrates the relationship between FF outlet temperature and mercury removal. As shown in the figure, mercury removal decreased with increasing FF outlet temperature. It can be inferred that mercury condensation/adsorption decreased at higher flue gas temperatures and, as a result, less mercury was captured with the particulate matter.

Because there was little variation in the FF pressure drop and mercury removal was consistently high (>96%), no significant correlation was observed between these two parameters. No correlation was found with % carbon in the FF ash (loss-on-ignition).

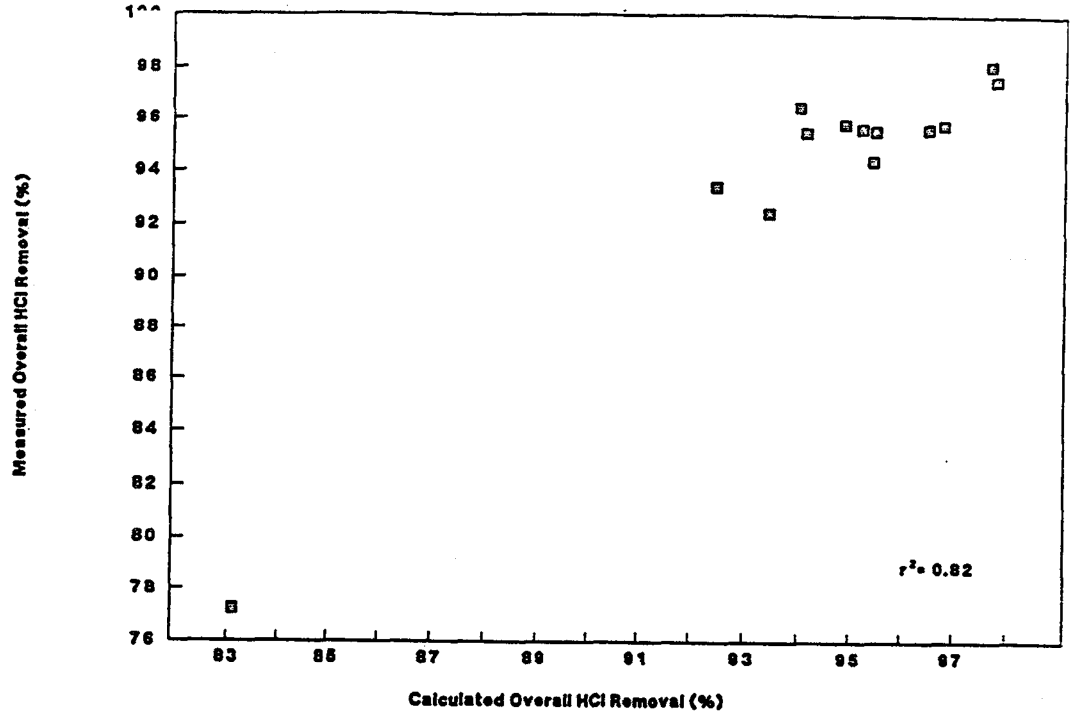


Figure 6-8. Measured Versus Calculated Overall HCl Removal Two Variable Model (RSR and SDOT)

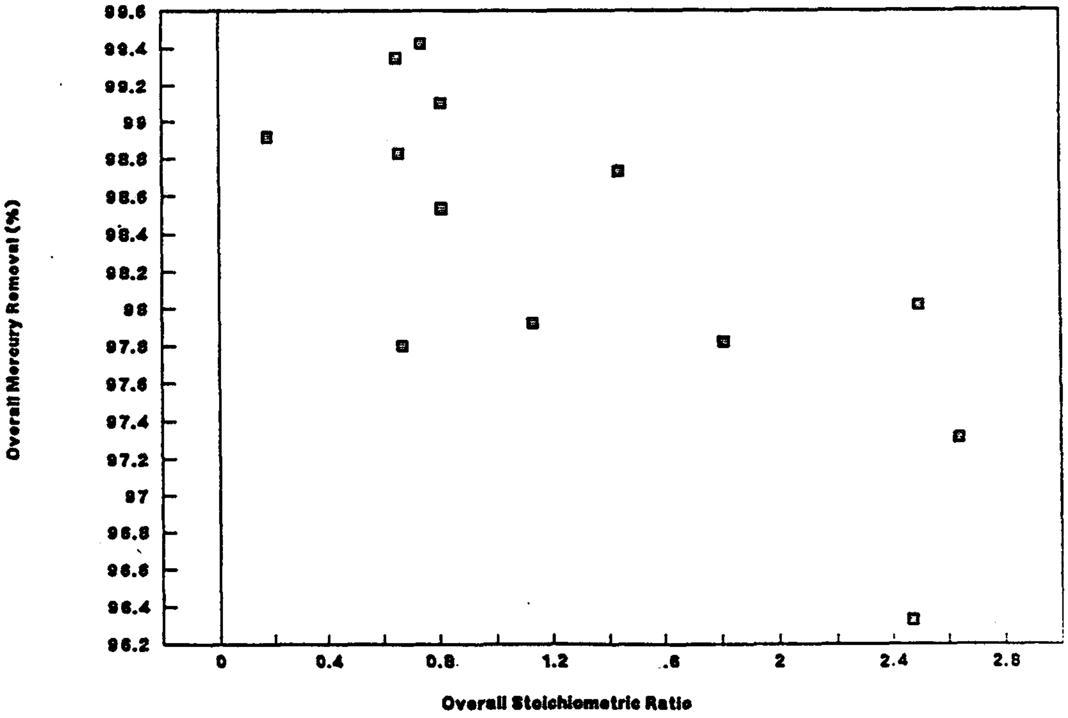


Figure 6-9. Overall Mercury Removal Versus Overall Stoichiometric Ratio

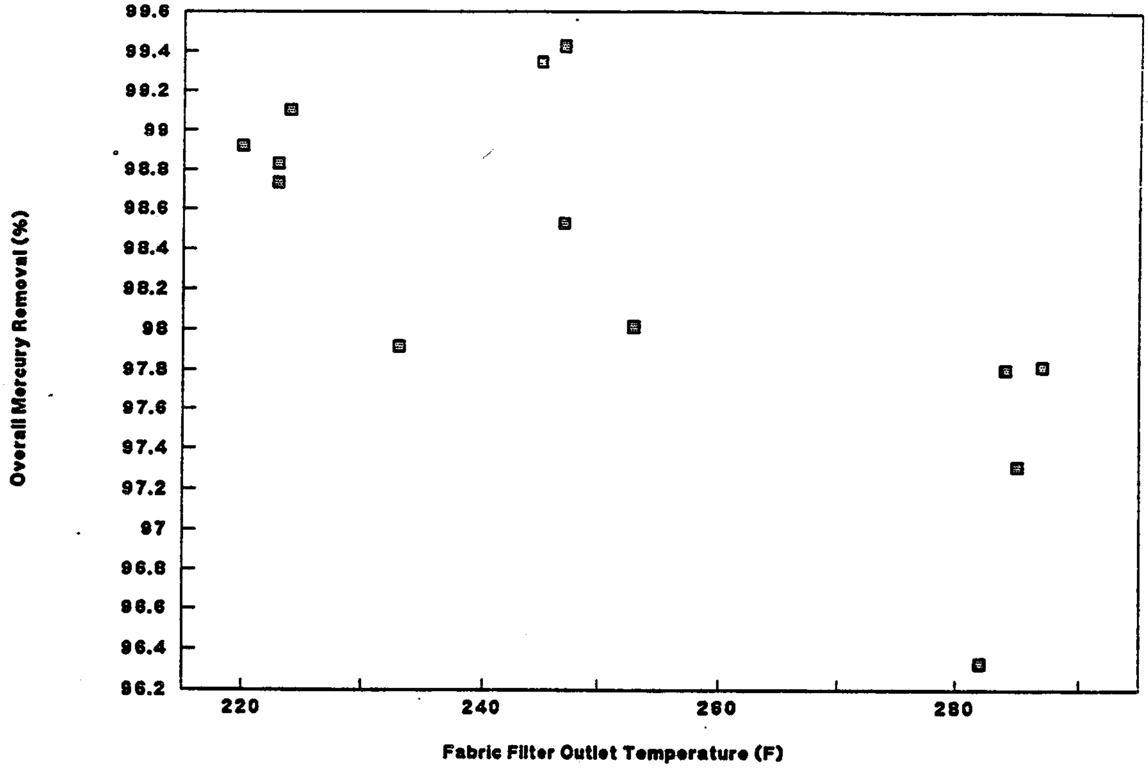


Figure 6-10. Overall Mercury Removal Versus FF Outlet Temperature

7 ASH CHARACTERIZATION RESULTS

7.1 OVERVIEW

The four separate ash streams, namely bottom ash (BA), grate siftings (GS), economizer (EC) ash and fabric filter (FF) ash, that were sampled during the thirteen performance tests were further tested as part of an ash characterization program. It should be noted that the ash products generated by the facility are combined and are currently disposed in a monofill, but no sampling nor analysis was done on this combined product. This section provides highlights of major findings of the ash characterization program and discusses implications for facility operation, ash management and recommendations for further study. The ash test program was conducted in three parts.

1. Analyses for trace organics and trace metals were conducted on ash samples from all thirteen performance tests. Detailed results are included in Volume II.
2. Chemical analyses of ash leachates generated using 4 different leaching/extraction tests were performed on samples from five of thirteen performance tests. A complete discussion of these analyses is included in Volume V, Book #1.
3. Chemical analyses and engineering tests were performed on solidified mixtures of fabric filter ash, waste pozzolanic material and Portland Type II cement. Solidification is one method of significant current interest for ultimate disposal and use of ash from these facilities. A complete discussion of the results is given in Volume V, Book #2.

7.2 CHEMICAL COMPOSITION ANALYSES

Trace organic concentrations in the ash streams have been presented in Chapter 5 for each performance test condition, and in Appendices A and B. The data are summarized in Table 7-1. Generally, there is a progressively significant increase in concentrations of all trace organics, except PAH, through the system, (i.e. highest for fabric filter ash and lowest for incinerator ash).

The range of distribution of most trace metals appears to be a function of thermal properties of the elements. For example, typically higher concentrations of relatively volatile trace metals such as arsenic, cadmium, mercury and zinc were measured in the fabric filter ash than in the bottom ash/grate siftings. However, relatively heat stable elements such as chromium, copper and nickel were generally measured in higher concentrations in the bottom ash/grate siftings. For lead, the highest concentrations were measured in the grate siftings. A fair correlation ($R^2 > .5$) was observed between concentrations in the bottom ash and grate sifting and concentrations in the refuse. Complete data are provided in Volumes II and V.

Additional analytical work to determine specific metal species present in the different fractions might promote better understanding of the effect of operating conditions on metal distribution.

Table 7-1. Summary of Average Trace Metal Concentrations (μg/g) in Ash

Metal	Dry Bottom Ash	Grate Siftings	Economizer	Fabric Filter Ash
Antimony	2	34	8	11
Arsenic	10	10	13	18
Cadmium	6	10	7	96
Chromium	211	325	301	216
Copper	5066	4036	888	491
Lead	1859	9645	893	2856
Mercury	0.15	1.2	0.02	34
Nickel	266	477	451	408
Zinc	136.9	2839	1591	6945

7.3 ACID NEUTRALIZATION CAPACITY

The acid neutralization capacity (ANC) of a material is a measure of that material's capacity to resist changes in pH, which is a relevant factor with regard to leachability of trace metals. The average ANC's of the ashes are shown in Figure 7-1 which indicate that the fabric filter ashes have higher buffering capacities than either the economizer ashes or the bottom/grate siftings ashes, which have very similar ANC's. The higher ANC values for the fabric filter ashes are due to the addition of lime slurry to the flue gas stream in the spray dryer. The high ANC values mean that in order to reduce the pH of fabric filter ash from its initial highly alkaline pH to a pH of 7.0, one gram of the ash would require contact with approximately 94 litres of acidic precipitation. It is estimated that it would take about 125 years for the pH of a 1 cm layer of fabric filter ash to drop to 7.0. This calculation is based on:

- an average precipitation pH of 4.5
- an assumed average annual rainfall of 1000 mm/year
- an assumed compacted density for fabric filter ash of 0.75 g/cm^3 (Sawell et al., 1989c),
- and, an assumed 100% infiltration rate of precipitation, which would be less in practice.

7.4 LEACHABILITY

Ash samples were subjected to the Sequential Batch Extraction Procedure (SBEP) to determine the potential organic and inorganic contaminant mobility in water over a wide range of liquid-to-solid ratios (20:1 to 100:1). Detailed information on the SBEP is contained in Volume V.

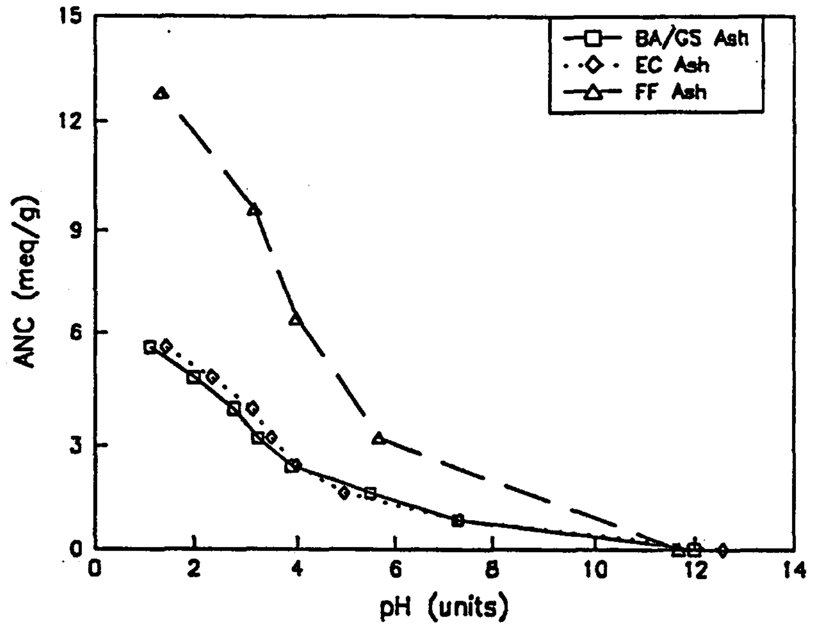


Figure 7-1. Average Acid Neutralization Capacity Results

7.4.1 Organic Contaminants

The maximum concentrations of organic contaminants in the composite leachates from the five cycles of the SBEP are presented in Table 7-2. Based on these results, the trace organic contaminants measured in the ashes are considered to be immobile in water.

Table 7-2. Maximum Detected Concentration of Trace Organics in Leachates

Trace Organics	Bottom Ash/Grate Siftings	Economizer Ash	Fabric Filter Ash
PCDD (ppt)	0.16*	0.06*	0.4*
PCDF (ppt)	0.17*	0.08*	0.3*
PAH (ppb)	0.17	0.14	0.06
PCB (ppb)	ND	ND	ND
CP (ppb)	0.29	0.06	0.09
CB (ppb)	ND	ND	ND

ND = Not detected
* = analyzed using high resolution GC/MS.

No PCB or CB was detected in any of the leachates from the SBEP. Very low concentrations (less than 0.3 ppb) of CP and PAH were detected in the leachates from all three types of ash. No PCDD or PCDF was detected in the leachates using standard analytical techniques; however, extremely low concentrations (less than 0.4 ppt) were detected in most of the leachates analyzed using high resolution GC/MS. The detected organic compounds are not considered soluble and were probably strongly bound to sub-micron sized particles which were not removed during sample filtration.

7.4.2 Inorganic Contaminants

The solubility of the ashes in water was determined by the sequential batch extraction procedure. The results in Figure 7-2 indicate that the bottom ash/grate siftings and economizer ashes were much less soluble in distilled water (about 7% of the solid dissolved) than the fabric filter ashes (about 34% dissolved). The higher solubility of the fabric filter ash is due to the lime and soluble flue gas condensation/reaction products which sorb onto the fly ash particles in the air pollution control system. A significant portion of the dissolved material from the fabric filter ashes consisted of sulphate and chloride (almost 14% sulphate and 27% chloride).

Metal solubility in distilled water was limited. No antimony, cadmium, cobalt, manganese, nickel or selenium were detected in any of the leachates. Of those metals that were detected, most represented small fractions (less than 10%) of the concentrations present in the ashes. Up to 60% of the very low concentrations of mercury present in the ashes was soluble during the SBEP. The limited solubility of the metals was due to the moderately alkaline pH of the leachates generated from the ashes. The different operating conditions did not appear to have any effect on metal leachability.

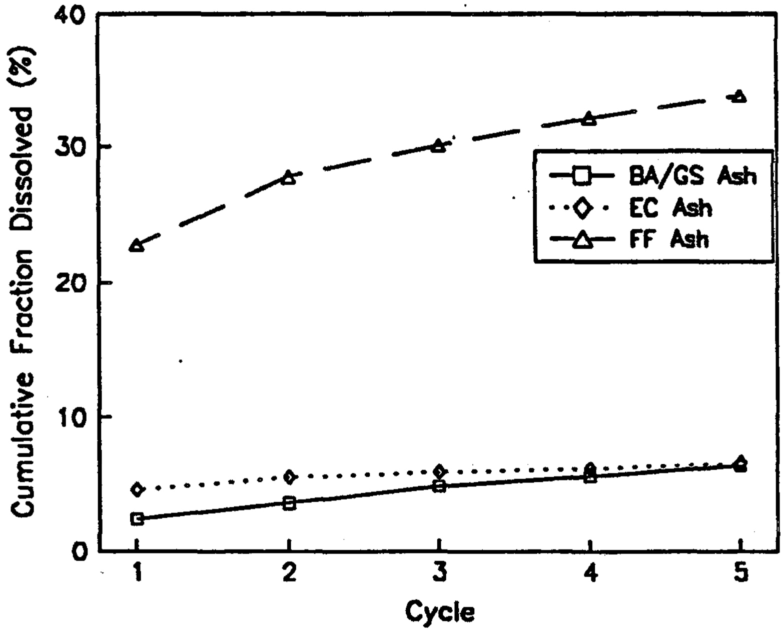


Figure 7-2. Average Cumulative Total Fraction of Solids Dissolved During the Sequential Batch Extraction Procedure

The leachability of metals from the ashes was also determined using the Sequential Chemical Extraction (SCE) Procedure, which is a step-wise separation of the total concentration of each metal into five distinct fractions using increasingly more aggressive leaching media to digest the solid material. The descriptions and interpretations related to each of the five fractions are summarized in Table 7-3.

Although the potential fraction of a metal measured in Fraction A is considered to be available for leaching upon contact with water, it is not indicative of the fraction which would be considered available for leaching under ash monofill disposal conditions over a prolonged period of time. The total potential fraction of a metal available for leaching under acidic conditions which may prevail in a municipal co-disposal landfill is assumed to be represented by the sum of Fractions A and B. It must be emphasized that the results from this test are only potential fractions and that these cannot be construed as field leachate concentrations that may occur under the conditions suggested (Table 7-3) and that the interpretations are assumed to be generalities.

Results from the SCE procedure indicate that none or only a very small fraction of the metals present in the ashes are considered available for leaching upon initial contact with water. Larger fractions of the metals are considered available for leaching under acidic conditions, especially in the fabric filter ash.

The SCE results indicate substantial differences in species profiles between the three types of ash. Slightly larger proportions of barium, copper, lead, manganese and nickel were measured in Fractions A and B of the economizer ashes than in Fractions A and B of the bottom ash/grate siftings ashes. In turn, larger proportions of barium, cadmium, chromium, manganese and zinc were measured in Fractions A and B of the fabric filter ashes than in Fractions A and B of the economizer ashes.

Table 7-3. Summary of the Sequential Chemical Extraction Procedure Descriptions and Interpretations

Fraction	Description	Interpretation
A	Ion exchangeable	Immediately available for leaching
B	Surface oxide and carbonate bound ions	Potentially available for leaching under acidic conditions
C	Iron and manganese bound metal ions	Potentially available for leaching under severe reducing conditions
D	Sulphide and organic matter bound ions	Unavailable for leaching under normal leaching conditions
E	Residual metal ions	Unavailable for leaching

There were no apparent differences in the species profiles for most metals in each ash type in the five test runs examined, with the notable exception of lead. The lead species profiles for bottom ash/grate siftings and fabric filter ash from the "good" and "poor" incinerator operating condition runs were considerably different. The species profiles for the two types of ash from the five test runs are given in Figure 7-3. Over 20% of the lead in the bottom ash/grate siftings ashes from PT5 and PT7 (poor operating conditions) were measured in Fractions A and B, whereas (with the exception of PT10) less than 9.3% of the lead in the bottom ash/grate siftings ashes from the good operating condition runs was measured in these fractions. Conversely, larger proportions of lead were measured in Fractions A and B of the fabric filter ash samples from PT8, PT9 or PT10 (good operating condition runs) than in those from the "poor" condition runs. These results indicate that the better operating conditions volatilized a greater proportion of the "heat reactive" lead from the waste which ultimately condensed out as potentially soluble lead compounds on the fabric filter ash particles.

The results from the Ontario Regulation 309 Leach Procedure and the Toxicity Characteristic Leaching Procedure indicate that if the ashes from this facility were subject to Ontario's regulatory requirements, which they are not, some of the bottom ash/grate siftings samples (PT7 and PT8) and all of the fabric filter ash samples from this facility would require special handling and disposal due to the leachable lead in bottom ash/grate siftings and cadmium in the fabric filter ashes.

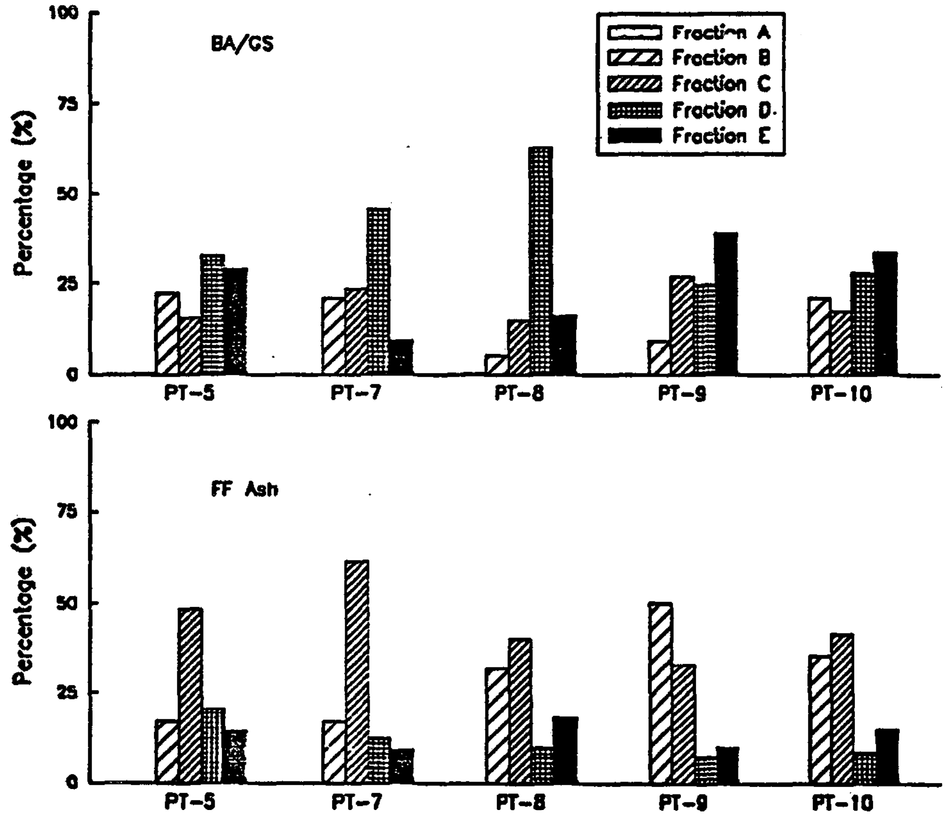


Figure 7-3. SCE Results for Lead From the Bottom Ash/Grate Siftings and Fabric Filter Ash

7.5 EVALUATION OF SOLIDIFIED FABRIC FILTER ASH

Solidification of ash is currently of significant interest as a technique for ultimate disposal and use of ash from municipal waste combustion facilities. The long-term environmental suitability of solidified mixtures of fabric filter ash, Portland Cement Type II and one of three types of waste pozzolanic material was characterized using chemical, leaching and standard cement engineering tests. Optimal formulations were selected based on the criterion that minimum quantities of solidifying agents be utilized, while still maintaining a sufficient physical strength.

The physical properties of the solidified specimens were tested after 56 days curing time using the following tests: moisture content, bulk density, solids specific gravity, hydraulic conductivity, unconfined compressive strength and freeze/thaw weathering tests. The results indicate that the solidified formulations produced specimens that (1) have a low volume change factor of about 1.0, (2) possess low hydraulic conductivities, (3) have sufficient unconfined compressive strength (greater than 50 pounds per square inch) for landfill disposal, and (4) are very durable.

The fabric filter ash and crushed samples of the three formulations were subjected to the Sequential Batch Extracting Procedure. The results indicate that solidification reduces the total solubility of the fabric filter ash beyond what would normally be expected due to dilution with the solidification agents. Much of this reduction is due to the transformation of readily soluble sulphate compounds to insoluble gypsum.

For most metals, the fraction solubilized by SBEP represented less than 1.0% of the total concentration of each metal present in the solidified ash. This was much less than for the untreated fabric filter ash. Conversely, the solubility of aluminum and mercury in the solidified material was equal to or higher than in the untreated fabric filter ash and is probably due to the chloride or hydroxide forms of these metals which are soluble under highly alkaline conditions.

The leachates from the SBEP were subjected to two different types of biological toxicity tests, both of which are given in detail in Volume V. Results indicated that solidification reduced the lethal toxicity of the fabric filter ash leachates. However, two of the solidification treatment leachates (i.e., CKD and FA) exhibited a genotoxic response. The appearance of a genotoxic response has not been explained.

Crushed samples of the three formulations were also subjected to the Government of Ontario Regulation 309 Leach Procedure and the Toxicity Characteristic Leaching Procedure (TCLP). The results indicate that concentrations of all metals in the solidified ash leachates from both tests were well below the Ontario guideline limits whereas concentrations of cadmium in the untreated fabric filter ash leachates exceeded the Ontario guideline limit by a factor of 6. Therefore, the untreated fabric filter ash from this facility would be classified as "hazardous", whereas the treated ashes would be considered non-hazardous.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 OVERVIEW

This chapter presents the most significant findings and conclusions from the Mid-Connecticut test program which are likely to be of interest to the general public and researchers.

Readers should be cognizant that the combustion and air pollution control systems at the facility were deliberately operated over a wide range of conditions as part of the test program. Hence, it would not be appropriate to "average the data" from many of the test runs when making judgments on normal operating conditions at this facility. Because of the time lag in collecting fabric filter ash, the elemental metal input/output or mass balance data are particularly difficult to reconcile. Nevertheless, general statements based on trends or ranges can be made when certain test data are carefully and scientifically grouped together. Also, it should be noted that the ash samples analyzed during this test program were taken from the location where the ash was generated. No testing of the combined ash product was conducted. This facility normally combines its ash for disposal.

8.2 GENERAL

1. Very low concentrations of trace organics, heavy metals, and acid gases in stack emissions were observed under all tested operating conditions. As an example, total PCDD/PCDF emissions were 1.5 ng/Sm^3 or less in all tests.

2. High removal efficiencies were attained for trace organics in the flue gas during all measurements between the spray dryer absorber inlet and fabric filter outlet. As an example, PCDD and PCDF removal efficiencies exceeded 99% for all tests.

3. Removal efficiencies for all metals in the flue gas, except mercury, typically exceeded 98%. For mercury, the removal efficiencies ranged from 96% to 99%.

4. RDF spreader stoker combustors can be operated with low CO concentrations under steady state conditions (i.e., excluding startup and shutdown). Average CO concentrations below 100 ppm were attained in a number of the completed 5 to 6 hour tests.

5. THC emissions below 7 ppm were achieved under "good combustion conditions". Combustion conditions which produced low CO emissions also produced low THC emissions.

6. Input/output (mass balance) comparisons of trace organic compounds in the RDF feed (input) with those in the ash and stack emissions (output) suggest that overall, combustion of RDF resulted in:

    a) a net reduction in PCDD, PAH, CP, CB, PCB,
    b) a net increase in PCDF, but
    c) a net decrease in total PCDD/PCDF.

The estimated average net destruction efficiencies for these trace organic compounds were 96% for good combustion conditions and 90% for poor combustion conditions.

7. No consistent evidence was obtained to substantiate PCDD/PCDF formation in the flue gas temperature range of 750 to 300° F (400 to 150°C) (measured across the airheater). This was contrary to what was expected for this temperature range.

8. As anticipated, flue gas temperature at the spray dryer outlet and (estimated) calcium hydroxide to acid gas ratio were found to be the most important operating parameters for controlling HCl and SO_2 emissions.

8.3 ASH RESULTS

1. The average loss on ignition (LOI) in bottom ash/grate siftings (0.7-1.5%) was lower than that measured in bottom ash from waterwall mass burn systems (1.5-5.0%) and much lower than in bottom ash from two stage combustion systems (12-30%).

2. Concentrations of PCDD/PCDF in the bottom ash and grate siftings were at or below the detection limit.

3. No PCB was detected in any of the ashes.

4. Trace organic contaminants were measured in the fabric filter ash. For example, over 99% of the total PCDD/PCDF associated with the residues was measured in the fabric filter ash.

5. PCDD/PCDF concentrations in fabric filter ash ranged from 70 to 509 ng/g. Although the statistical correlation was not significant, inspection of these data suggests that good combustion conditions tend to result in comparatively low PCDD/PCDF concentrations in the fabric filter ash.

6. Organic contaminants in the ashes, including PCDD, PCDF, CB, and PAH, were not soluble in water.

7. Typically, concentrations of less volatile metals (e.g., Cr, Ni, Cu) were higher in the combined bottom ash/grate siftings, whereas concentrations of relatively volatile metals (e.g., Cd, Hg, Zn) were higher in the fabric filter ash. Lead concentrations were:

   a) relatively high in both grate siftings and fabric filter ash,
   b) relatively low in the bottom and in economizer ashes.

8. Fabric filter ash was more soluble in water (approximately 34% solubilized) than either the combined bottom ash/grate siftings or economizer ashes (approximately 7% solubilized). A substantial portion of the solubilized material from the fabric filter ash consisted of sulphate and chloride anions (14% sulphate and 27% chloride).

9. Only very small amounts (typically less than 10%) of most trace metals present in the ashes were soluble in water.

10. In general, under simulated acidic conditions, larger fractions of Cd, Cr, Pb, Mn, and Zn, were potentially available for leaching from the fabric filter ash than from the bottom and grate siftings ashes. However, it should be noted that under most controlled disposal conditions, an acidic leaching environment is unlikely given the high acid neutralization capacity of the fabric filter ash.

11. Fabric filter ash was solidified using cement and three types of waste pozzolanic materials. Engineering test results indicate that these solidified materials were physically strong, durable, and relatively impermeable. In addition, results from different leach tests indicate a significant reduction in metal mobility was achieved through both physical encapsulation and chemical fixation.

8.4 CORRELATIONS

Single-value regression analysis, comparing all test parameters with one another, was conducted to investigate possible correlations. In addition, multiple regression analysis of selected test data was conducted for two main purposes:

a) To investigate the feasibility of using easily-monitored variables, either individually or in clusters, as surrogate measures of difficult-to-monitor variables. This was done by choosing a difficult-to-monitor chemical, such as PCDD, as the dependent variable and easily-monitored variables such as SO_2 and CO as independent variables in the multiple regression equation.

b) To explore the individual and collective influence of various operation controls on the emissions of certain compounds. This was done by choosing an emitted chemical as the dependant variable and selecting operating conditions as independent variables in the multiple regression equation.

Key results of the regression analysis are as follows:

1. Moderate correlations were observed for CO and THC versus PCDD/PCDF at spray dryer inlet over the entire data set ($R^2 = 0.7$ and 0.68 respectively). An excellent correlation ($R^2 = 0.95$) was observed for CO versus PCDD/PCDF when CO emissions were over 200 ppm, although no correlation was observed when CO emission concentrations were less than 200 ppm. Similarly, THC emissions above 7 ppm correlated excellently with PCDD/PCDF ($R^2 = 0.97$), but no correlation was found between these emissions when THC concentrations are less than 7 ppm.

2. When comparing CO emissions with PCDD/PCDF emissions, the arithmetic average of CO emissions over the testing period provides the best correlation with PCDD/PCDF concentrations at the spray dryer inlet. However, the correlation was poor where CO averaged below 200 ppm for the test period. Other comparisons of PCDD/PCDF concentrations with the number or magnitude of CO spikes and the percent of time above an absolute CO level produced less significant correlations.

3. Multiple regression analysis show that the best easily-monitored variable for correlating concentrations of PCDD, PCDF, CP, CB, and PAH at the spray dryer inlet typically include any two or more of the following:

   a) CO
   b) THC
   c) NO_x
   d) HCl
   e) H_2O in flue gas
   f) Temperature in furnace or at economizer outlet

   For example, the best correlation for PCDD concentrations ($R^2 = 0.9$) at the spray dryer inlet is based on CO, NO_x, and H_2O concentrations in the flue gas.

4. Multiple regressions based on combustor operating variables that best explained the variation in concentrations of PCDD, PCDF, CP, CB, and PAH at the spray dryer inlet, use a combination of operating variables. These operating variables are also good indicators of conditions within the furnace and relate to fundamental combustion conditions (time, temperature, air/fuel ratio and mixing).

5. Multiple regression analyses based on easily-monitored variables ("good" to "excellent" range, $R^2 = 0.8$ to 0.98 respectively) were more conclusive than those based on combustor operating variables ("fair" to "good" range, $R^2 = 0.6$ to 0.8 respectively).

6. A fair correlation ($R^2 = 0.61$) was obtained between PCDD/PCDF and particulate matter concentrations at the spray dryer inlet under good combustion conditions.

7. Poor correlations of uncontrolled PCDD/PCDF concentrations were observed under all combustion conditions for the following parameters:

   a) loss on ignition (LOI) in economizer ash,
   b) HCl at the spray dryer inlet, and
   c) copper concentrations in fly ash.

8. The removal of trace organic compounds by the flue gas cleaning system correlated best with increased sorbent-to-acid-gas ratio (stoichiometric ratio) and decreasing spray dryer outlet temperature. These same variables were also seen to correlate with the degree of acid gas control.

9. Multiple regression analyses showed a very good correlation ($R^2 = 0.89$) between mercury removal by the flue gas cleaning system and decreasing flue gas temperature (spray dryer outlet) and increasing LOI of the fabric filter ash. Increases in stoichiometric ratio appeared to cause increased Hg emissions.

8.5 RECOMMENDATIONS

1. The importance of the refuse quantity and quality on emissions and residues needs to be better assessed and quantified.

2. Research is required to identify the major contributors of metals to the waste stream and to document the impact on the ultimate quality of the different ash and emissions streams of source separation, recycling and front-end processing of waste prior to combustion.

3. Research on speciation of metals before (refuse feed) and after the combustion process (ash) should be conducted to determine the impact of feed materials on ash quality and to determine effective removal process for volatile species in flue gas.

4. The results of a study on household hazardous waste demonstrate that incineration is effective in destroying trace organic compounds (>96% under good combustion conditions, >90% under poor combustion conditions). The results also demonstrate that the air pollution control system is highly efficient in removing the organics in flue gases (>99%). These findings indicate that incineration may be an effective disposal option for trace organic compounds commonly found in household hazardous waste. Future research should be directed at examining the amounts and characteristics of household hazardous waste in the waste stream and the impacts on incinerator air emissions and ash residue.

5. A reliable method to determine the carbon content in fly ash is required for assessing incomplete products of combustion. This would determine if LOI is a suitable method for determining products of incomplete combustion.

6. Definitive stoichiometric ratio data should be obtained for evaluating flue gas cleaning system performance at MWC facilities. Stoichiometric ratio is recognized to be a very important parameter in the control of acid gases and possibly trace organics.

7. The impact of high sorbent stoichiometric ratio (> 2) in spray dryer absorber fabric filter systems should be investigated to determine its effect on fabric filter ash solubility and Hg capture.

8. The potential for artifact formation of PCDD/PCDF in the EPA MM5 sampling train at high temperatures [>400°F (200°C)] should be further investigated. This investigation may explain the decrease of PCDD/PCDF concentrations measured between the air heater inlet and spray dryer inlet.

9. Research should be undertaken on the characteristics of particles in the flue gas entering the air pollution control system, including studies of particle size distribution, metals speciation and organic content.

10. A thorough environmental characterization, such as performed in this study, should be completed on waste recycling technologies.

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APPENDIX A

COMBUSTION SYSTEM SUMMARY BY PERFORMANCE TEST CONDITION

Appendix A-1.

COMBUSTION SYSTEM SUMMARY

LOW LOAD / GOOD OPERATING CONDITIONS

PT 13/14

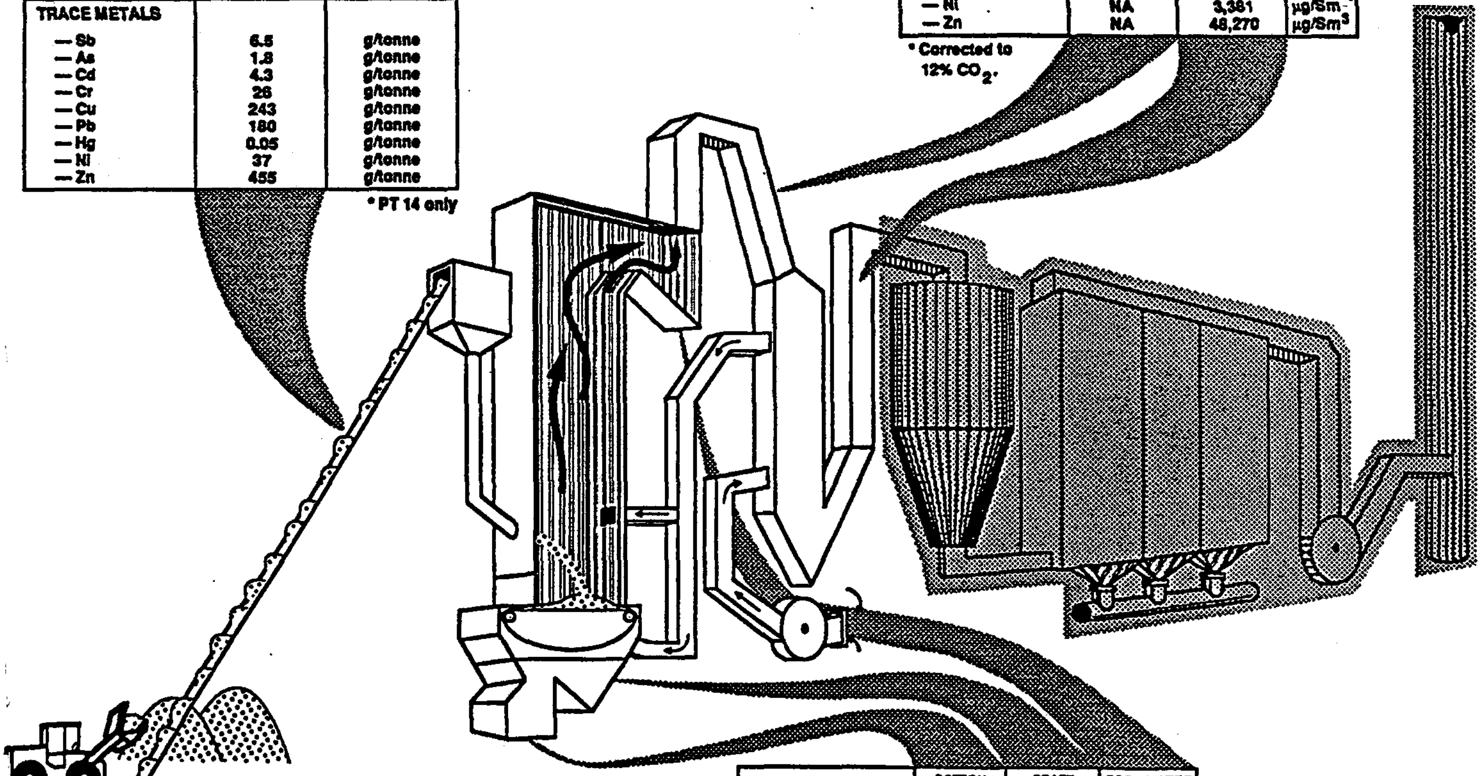
COMBUSTION SYSTEM OPERATING CONDITIONS		
STEAM FLOW	160	klb/h
TEMPERATURE		
— Furnace	985	°C
— Boiler Inlet	588	°C
— Economizer Outlet	356	°C
— Air Heater Outlet	186	°C
UNDERGRATE : OVERFIRE AIR RATIO	52:48	%
EFFICIENCY		
— Output/Input	71.18	%

REFUSE DERIVED FUEL		
FEED RATE	18,939	kg/h
MOISTURE	17.1	%, wet, as fired*
HHV	5,881	Btu/lb, wet
TRACE ORGANICS		
— PCDD	6.3	mg/tonne
— PCDF	0.17	mg/tonne
— PCB	ND	mg/tonne
— CB	22	mg/tonne
— CP	626	mg/tonne
— PAH	57,088	mg/tonne
TRACE METALS		
— Sb	6.5	g/tonne
— As	1.8	g/tonne
— Cd	4.3	g/tonne
— Cr	26	g/tonne
— Cu	243	g/tonne
— Pb	180	g/tonne
— Hg	0.05	g/tonne
— Ni	37	g/tonne
— Zn	455	g/tonne

* PT 14 only

FLUE GAS	PREHEATER INLET	SPRAY DRYER INLET	
GAS			
— FLOW	NA	133,374	Sm^3/h
— TEMPERATURE	NA	191	°C
— MOISTURE	NA	12.2	%
CONTINUOUS MONITORS			
— O_2	NA	9.9	%
— CO_2	NA	10.0	%
— CO	NA	114	ppm
— NO_x	NA	167	ppm
— SO_2	NA	182	ppm
— HCl	NA	432	ppm
— THC	NA	4.7	ppm
TRACE ORGANICS			
— PCDD	NA	109	ng/Sm^3*
— PCDF	NA	404	ng/Sm^3*
— PCB	NA	ND	ng/Sm^3*
— CB	NA	3,957	ng/Sm^3*
— CP	NA	13,311	ng/Sm^3*
— PAH	NA	3,516	ng/Sm^3*
PARTICULATE	NA	3,453.3	mg/Sm^3*
TRACE METALS			
— Sb	NA	113	µg/Sm^3*
— As	NA	205	µg/Sm^3*
— Cd	NA	573	µg/Sm^3*
— Cr	NA	1,050	µg/Sm^3*
— Cu	NA	2,010	µg/Sm^3*
— Pb	NA	10,826	µg/Sm^3*
— Hg	NA	723	µg/Sm^3*
— Ni	NA	3,381	µg/Sm^3*
— Zn	NA	48,270	µg/Sm^3

* Corrected to 12% CO_2.



ASH	BOTTOM ASH	GRATE SIFTINGS	ECONOMIZER	
ASH RATE (dry)	2,373	89	12.7	kg/h
TRACE ORGANICS				
— PCDD	ND		ND	ng/g
— PCDF	ND		ND	ng/g
— PCB	ND		ND	ng/g
— CB	ND		ND	ng/g
— CP	10		24	ng/g
— PAH	44		ND	ng/g
TRACE METALS				
— Sb	1.7	21	8.1	µg/g
— As	12	9.7	14.4	µg/g
— Cd	9.1	8.8	6.5	µg/g
— Cr	316	297	310	µg/g
— Cu	4,369	3,958	1,130	µg/g
— Pb	3,601	8,545	940	µg/g
— Hg	ND	0.56	0.028	µg/g
— Ni	333	432	660	µg/g
— Zn	1,877	1,628	1,819	µg/g

Appendix A-2.

COMBUSTION SYSTEM SUMMARY

INTERMEDIATE LOAD / GOOD OPERATING CONDITIONS

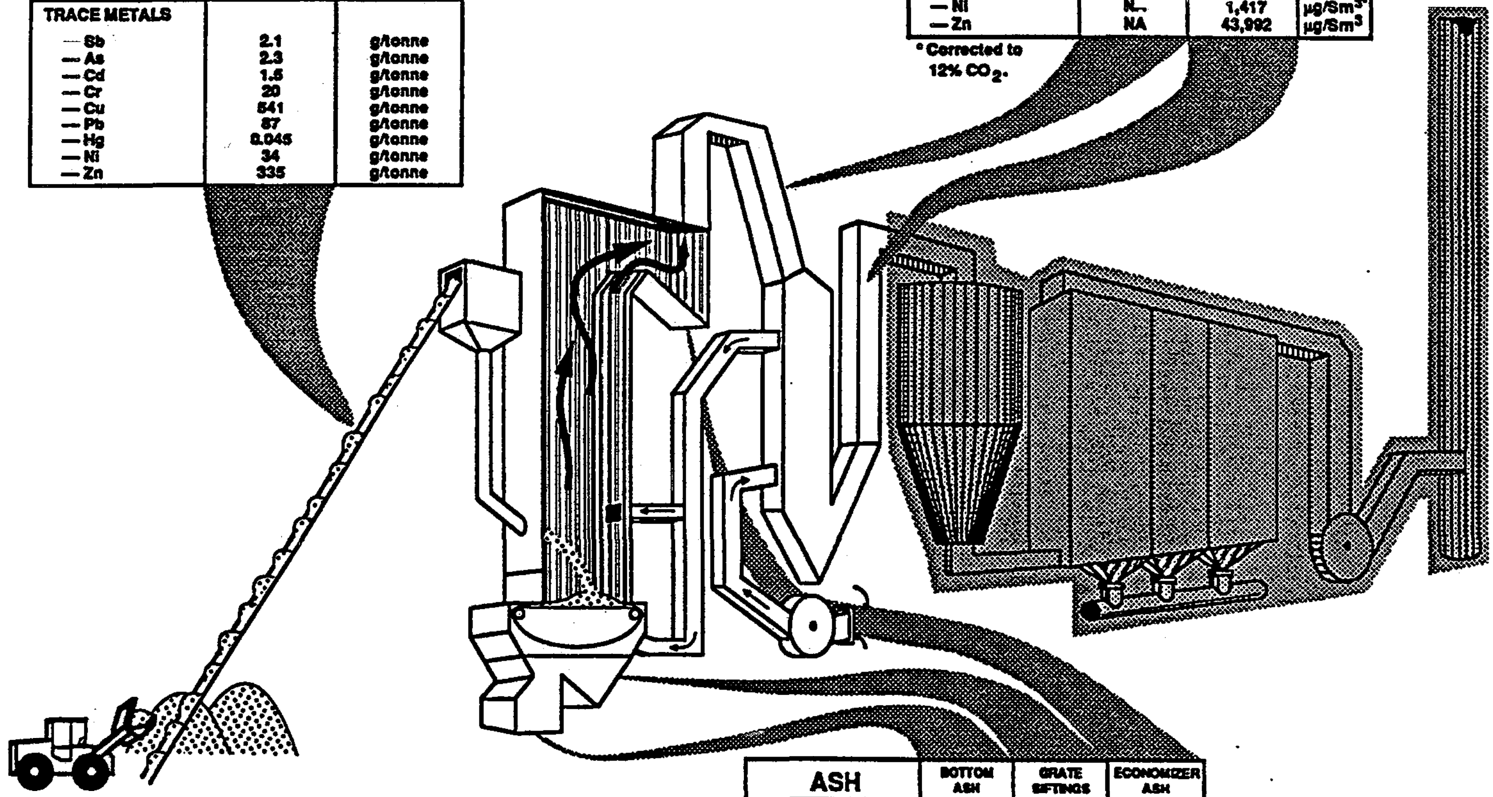
PT 02/10

COMBUSTION SYSTEM OPERATING CONDITIONS		
STEAM FLOW	193	klb/h
TEMPERATURE		
— Furnace	1,016	°C
— Boiler Inlet	605	°C
— Economizer Outlet	384	°C
— Air Heater Outlet	193	°C
UNDERGRATE : OVERFIRE AIR RATIO	48:52	%
EFFICIENCY		
— Output/Input	53.99	%

FLUE GAS	PREHEATER INLET	SPRAY DRYER INLET	
GAS			
— FLOW	NA	154,014	Sm^3/h
— TEMPERATURE	NA	192	°C
— MOISTURE	NA	14.1	%
CONTINUOUS MONITORS			
— O_2	NA	9.2	%
— CO_2	NA	10.5	%
— CO	NA	93	ppm
— NO_x	NA	185	ppm
— SO_2	NA	186	ppm
— HCl	NA	450	ppm
— THC	NA	2.5	ppm
TRACE ORGANICS			
— PCDD	174	228	ng/Sm^{3*}
— PCDF	816	579	ng/Sm^{3*}
— PCB	252	20	ng/Sm^{3*}
— CB	12,030	6,045	ng/Sm^{3*}
— CP	21,181	14,253	ng/Sm^{3*}
— PAH	10,512	7,333	ng/Sm^{3*}
PARTICULATE	NA	4,985.8	mg/Sm^{3*}
TRACE METALS			
— Sb	NA	120	µg/Sm^{3*}
— As	NA	240	µg/Sm^{3*}
— Cd	NA	584	µg/Sm^{3*}
— Cr	NA	983	µg/Sm^{3*}
— Cu	NA	1,992	µg/Sm^{3*}
— Pb	NA	8,714	µg/Sm^{3*}
— Hg	NA	722	µg/Sm^{3*}
— Ni	N..	1,417	µg/Sm^{3*}
— Zn	NA	43,992	µg/Sm^3

* Corrected to 12% CO_2.

REFUSE DERIVED FUEL		
FEED RATE	26,830	kg/h
MOISTURE	21.9	%, wet, as fired
HHV	5,704	Btu/lb, wet
TRACE ORGANICS		
— PCDD	2.5	mg/tonne
— PCDF	0.087	mg/tonne
— PCB	57	mg/tonne
— CB	13	mg/tonne
— CP	473	mg/tonne
— PAH	5,137	mg/tonne
TRACE METALS		
— Sb	2.1	g/tonne
— As	2.3	g/tonne
— Cd	1.5	g/tonne
— Cr	20	g/tonne
— Cu	541	g/tonne
— Pb	87	g/tonne
— Hg	0.045	g/tonne
— Ni	34	g/tonne
— Zn	335	g/tonne



ASH	BOTTOM ASH	GRATE SIFTINGS	ECONOMIZER ASH	
ASH RATE (dry)	3,088	115.5	16.7	kg/h
TRACE ORGANICS				
— PCDD	ND		ND	ng/g
— PCDF	ND		0.029	ng/g
— PCB	ND		ND	ng/g
— CB	ND		ND	ng/g
— CP	12		15	ng/g
— PAH	6,432		6.0	ng/g
TRACE METALS				
— Sb	ND	26	10	µg/g
— As	10	10	12	µg/g
— Cd	6	8.7	8	µg/g
— Cr	184	409	245	µg/g
— Cu	6,712	9,365	650	µg/g
— Pb	1,247	12,894	785	µg/g
— Hg	0.04	0.45	0.01	µg/g
— Ni	337	693	355	µg/g
— Zn	1,623	3,242	1,200	µg/g

Appendix A-3.

COMBUSTION SYSTEM SUMMARY

INTERMEDIATE LOAD / VERY POOR OPERATING CONDITIONS

PT 05

COMBUSTION SYSTEM OPERATING CONDITIONS

STEAM FLOW	184	klb/h
TEMPERATURE		
— Furnace	1,020	°C
— Boiler Inlet	605	°C
— Economizer Outlet	367	°C
— Air Heater Outlet	190	°C
UNDERGRATE : OVERFIRE AIR RATIO	62:38	%
EFFICIENCY		
— Output/Input	50.65	%

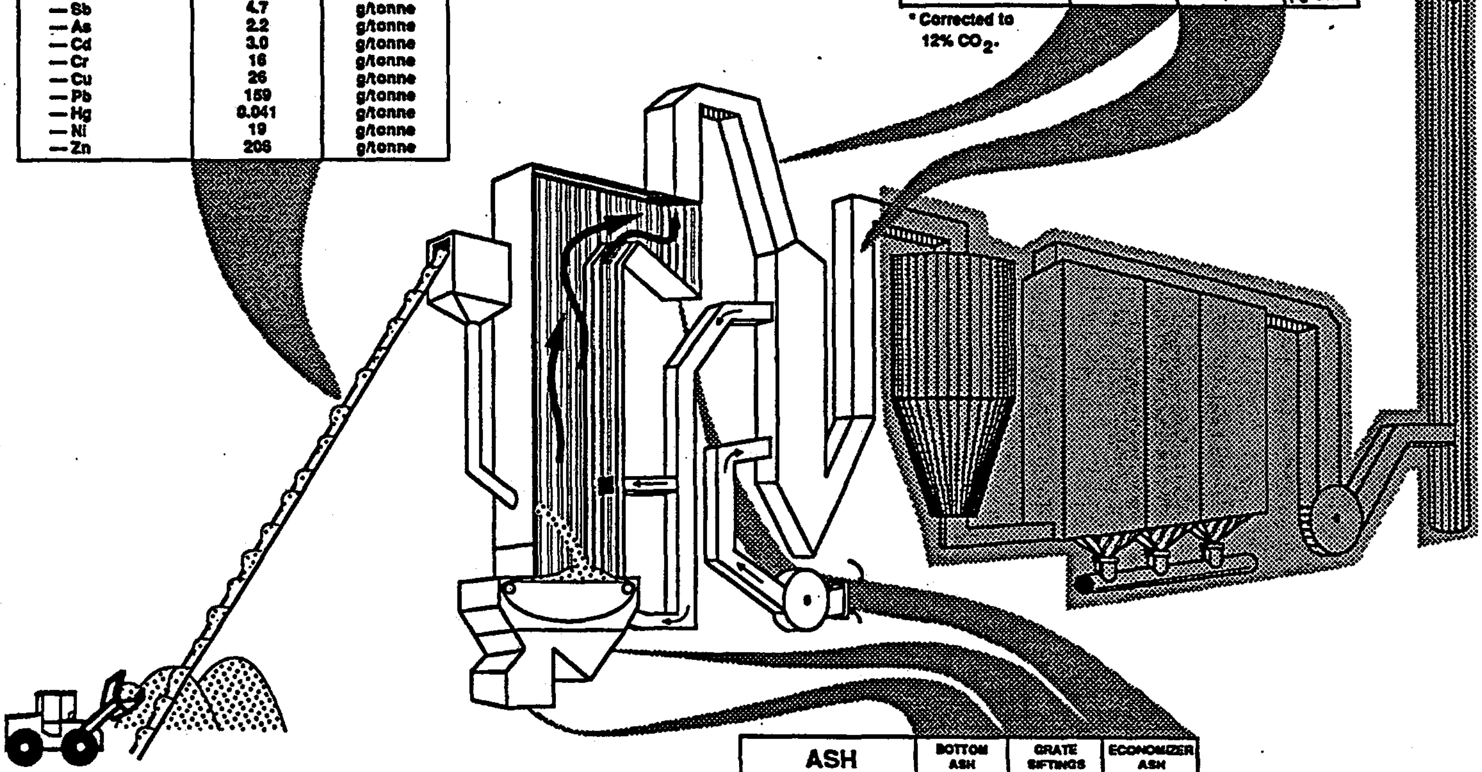
FLUE GAS

FLUE GAS	PREHEATER INLET	SPRAY DRYER INLET	
GAS			
— FLOW	NA	146,831	Sm³/h
— TEMPERATURE	NA	189	°C
— MOISTURE	NA	13.3	%
CONTINUOUS MONITORS			
— O_2	NA	8.7	%
— CO_2	NA	11.0	%
— CO	NA	535	ppm
— NO_x	NA	149	ppm
— SO_2	NA	169	ppm
— HCl	NA	469	ppm
— THC	NA	52.4	ppm
TRACE ORGANICS			
— PCDD	NA	580	ng/Sm³*
— PCDF	NA	1,281	ng/Sm³*
— PCB	NA	20	ng/Sm³*
— CB	NA	15,801	ng/Sm³*
— CP	NA	113,568	ng/Sm³*
— PAH	NA	111,975	ng/Sm³*
PARTICULATE	NA	4,457.96	mg/Sm³*
TRACE METALS			
— Sb	NA	122	µg/Sm³*
— As	NA	230	µg/Sm³*
— Cd	NA	527	µg/Sm³*
— Cr	NA	623	µg/Sm³*
— Cu	NA	1,429	µg/Sm³*
— Pb	NA	14,286	µg/Sm³*
— Hg	NA	634	µg/Sm³*
— Ni	NA	2,030	µg/Sm³*
— Zn	NA	31,169	µg/Sm³

* Corrected to 12% CO_2.

REFUSE DERIVED FUEL

FEED RATE	27,043	kg/h
MOISTURE	23.3	%, wet, as fired
HHV	5,233	Btu/lb, wet
TRACE ORGANICS		
— PCDD	5.2	mg/tonne
— PCDF	ND	mg/tonne
— PCB	194	mg/tonne
— CB	22	mg/tonne
— CP	625	mg/tonne
— PAH	4,065	mg/tonne
TRACE METALS		
— Sb	4.7	g/tonne
— As	2.2	g/tonne
— Cd	3.0	g/tonne
— Cr	16	g/tonne
— Cu	26	g/tonne
— Pb	159	g/tonne
— Hg	0.041	g/tonne
— Ni	19	g/tonne
— Zn	206	g/tonne



ASH

ASH	BOTTOM ASH	GRATE SIFTINGS	ECONOMIZER ASH	
ASH RATE (dry)	2,828	103	13.8	kg/h
TRACE ORGANICS				
— PCDD	ND		0.43	ng/g
— PCDF	ND		1.83	ng/g
— PCB	ND		ND	ng/g
— CB	ND		ND	ng/g
— CP	15		10	ng/g
— PAH	76		475	ng/g
TRACE METALS				
— Sb	1.1	25.5	13	µg/g
— As	10.5	8.1	15	µg/g
— Cd	6	11	5.9	µg/g
— Cr	196	454	330	µg/g
— Cu	3,835	956	679	µg/g
— Pb	1,913	3,881	949	µg/g
— Hg	ND	2.0	0.02	µg/g
— Ni	294	1,136	1,289	µg/g
— Zn	1,153	1,789	1,408	µg/g

Appendix A-4.

COMBUSTION SYSTEM SUMMARY

NORMAL LOAD / GOOD OPERATING CONDITIONS

PT 08/09/11

COMBUSTION SYSTEM OPERATING CONDITIONS

STEAM FLOW	211	klb/h
TEMPERATURE		
— Furnace	1,025	°C
— Boiler Inlet	574	°C
— Economizer Outlet	377	°C
— Air Heater Outlet	194	°C
UNDERGRATE : OVERFIRE AIR RATIO	50:50	%
EFFICIENCY		
— Output/Input	60.16	%

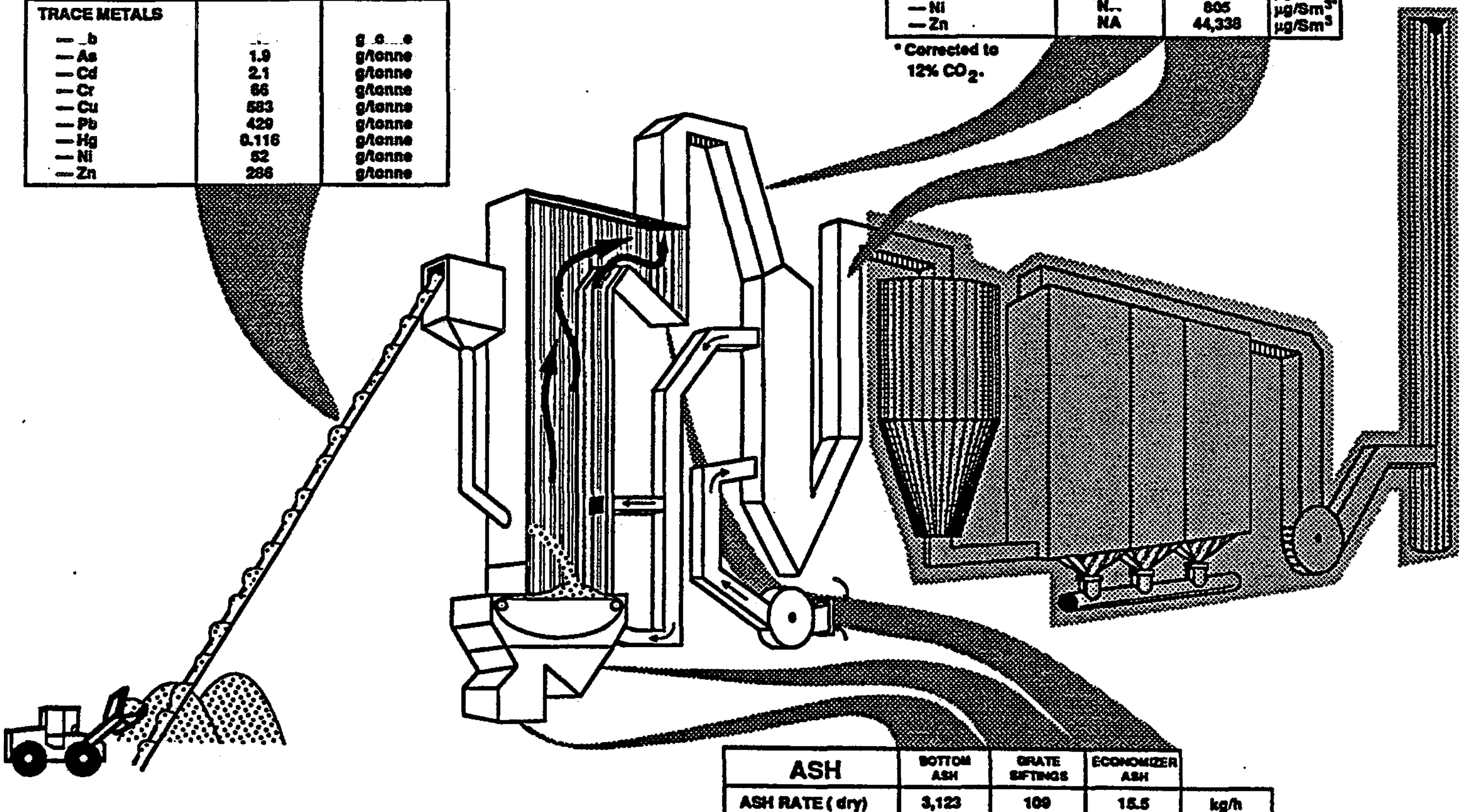
REFUSE DERIVED FUEL

FEED RATE	28,170	kg/h
MOISTURE	23.7	%, wet, as fired
HHV	5,704	Btu/lb, wet
TRACE ORGANICS		
— PCDD	3.5	mg/tonne
— PCDF	0.34	mg/tonne
— PCB	270	mg/tonne
— CB	5.9	mg/tonne
— CP	452	mg/tonne
— PAH	4,640	mg/tonne
TRACE METALS		
— Sb	[illegible]	g/tonne
— As	1.9	g/tonne
— Cd	2.1	g/tonne
— Cr	66	g/tonne
— Cu	583	g/tonne
— Pb	429	g/tonne
— Hg	0.116	g/tonne
— Ni	52	g/tonne
— Zn	286	g/tonne

FLUE GAS

FLUE GAS	PREHEATER INLET	SPRAY DRYER INLET	
GAS			
— FLOW	NA	147,679	Sm^3/h
— TEMPERATURE	NA	194	°C
— MOISTURE	NA	15.5	%
CONTINUOUS MONITORS			
— O_2	NA	7.7	%
— CO_2	NA	11.8	%
— CO	NA	83	ppm
— NO_x	NA	185	ppm
— SO_2	NA	179	ppm
— HCl	NA	461	ppm
— THC	NA	3.3	ppm
TRACE ORGANICS			
— PCDD	200	125	ng/Sm^{3*}
— PCDF	1,297	591	ng/Sm^{3*}
— PCB	100	33	ng/Sm^{3*}
— CB	12,373	5,482	ng/Sm^{3*}
— CP	38,966	14,322	ng/Sm^{3*}
— PAH	44,827	16,462	ng/Sm^{3*}
PARTICULATE	NA	4,207.21	mg/Sm^{3*}
TRACE METALS			
— Sb	NA	135	µg/Sm^{3*}
— As	NA	211	µg/Sm^{3*}
— Cd	NA	694	µg/Sm^{3*}
— Cr	NA	984	µg/Sm^{3*}
— Cu	NA	2,531	µg/Sm^{3*}
— Pb	NA	5,164	µg/Sm^{3*}
— Hg	NA	650	µg/Sm^{3*}
— Ni	N..	805	µg/Sm^{3*}
— Zn	NA	44,338	µg/Sm^{3}

* Corrected to 12% CO_2.



ASH

ASH	BOTTOM ASH	GRATE SIFTINGS	ECONOMIZER ASH	
ASH RATE (dry)	3,123	109	15.5	kg/h
TRACE ORGANICS				
— PCDD	0.18		0.061	ng/g
— PCDF	0.17		0.38	ng/g
— PCB	ND		ND	ng/g
— CB	ND		ND	ng/g
— CP	2.5		13	ng/g
— PAH	16		14	ng/g
TRACE METALS				
— Sb	1.9	37	3.2	µg/g
— As	10	11	11	µg/g
— Cd	7	10	7.3	µg/g
— Cr	204	282	400	µg/g
— Cu	4,545	2,337	1,540	µg/g
— Pb	2,399	9,733	923	µg/g
— Hg	ND	0.98	0.14	µg/g
— Ni	211	401	377	µg/g
— Zn	1,395	2,277	1,933	µg/g

Appendix A-5.

COMBUSTION SYSTEM SUMMARY

NORMAL LOAD / POOR OPERATING CONDITIONS

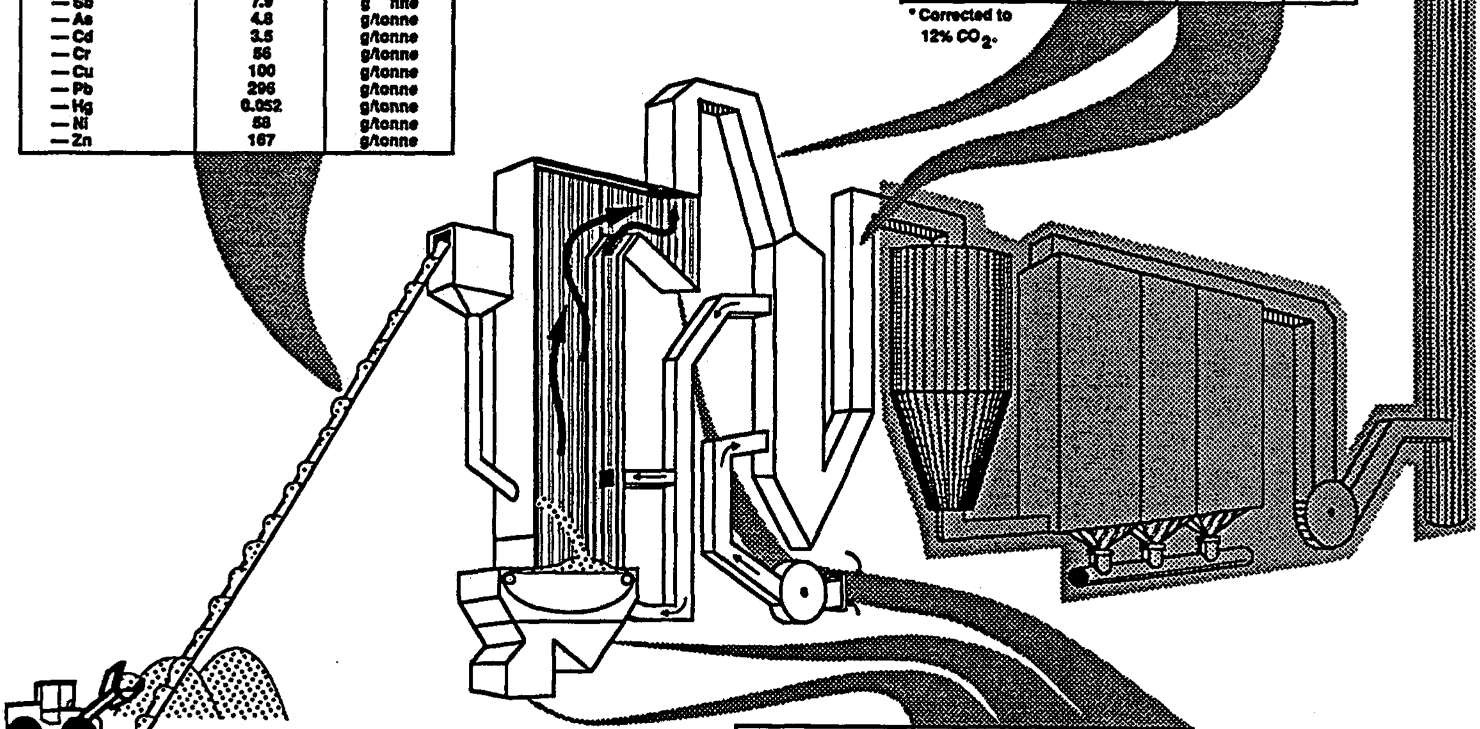
PT 03/04/07

COMBUSTION SYSTEM OPERATING CONDITIONS		
STEAM FLOW	220	klb/h
TEMPERATURE		
— Furnace	1,033	°C
— Boiler Inlet	579	°C
— Economizer Outlet	376	°C
— Air Heater Outlet	202	°C
UNDERGRATE : OVERFIRE AIR RATIO	50:50	%
EFFICIENCY		
— Output/Input	58.87	%

FLUE GAS	PREHEATER INLET	SPRAY DRYER INLET	
GAS			
— FLOW	NA	153,452	Sm³/h
— TEMPERATURE	NA	199	°C
— MOISTURE	NA	16.0	%
CONTINUOUS MONITORS			
— O_2	NA	7.2	%
— CO_2	NA	12.0	%
— CO	NA	308	ppm
— NO_x	NA	168	ppm
— SO_2	NA	189	ppm
— HCl	NA	430	ppm
— THC	NA	13.9	ppm
TRACE ORGANICS			
— PCDD	390	196	ng/Sm³*
— PCDF	1,932	732	ng/Sm³*
— PCB	269	11	ng/Sm³*
— CB	13,954	6,944	ng/Sm³*
— CP	59,256	24,106	ng/Sm³*
— PAH	88,865	53,846	ng/Sm³*
PARTICULATE	NA	4,049.4	mg/Sm³*
TRACE METALS			
— Sb	NA	60	µg/Sm³*
— As	NA	186	µg/Sm³*
— Cd	NA	552	µg/Sm³*
— Cr	NA	539	µg/Sm³*
— Cu	NA	1,531	µg/Sm³*
— Pb	NA	10,211	µg/Sm³*
— Hg	NA	594	µg/Sm³*
— Ni	N..	503	µg/Sm³*
— Zn	NA	35,563	µg/Sm³

* Corrected to 12% CO_2.

REFUSE DERIVED FUEL		
FEED RATE	29,299	kg/h
MOISTURE	23.8	%, wet, as fired
HHV	5,883	Btu/lb, wet
TRACE ORGANICS		
— PCDD	3.9	mg/tonne
— PCDF	0.058	mg/tonne
— PCB	ND	mg/tonne
— CB	702	mg/tonne
— CP	580	mg/tonne
— PAH	5,542	mg/tonne
TRACE METALS		
— Sb	7.9	g nne
— As	4.8	g/tonne
— Cd	3.5	g/tonne
— Cr	56	g/tonne
— Cu	100	g/tonne
— Pb	296	g/tonne
— Hg	0.052	g/tonne
— Ni	58	g/tonne
— Zn	167	g/tonne



ASH	BOTTOM ASH	GRATE SIFTING**	ECONOMIZER ASH	
ASH RATE (dry)	3,550	115	13.5	kg/h
TRACE ORGANICS				
— PCDD	ND		ND	ng/g
— PCDF	ND		0.35	ng/g
— PCB	ND		ND	ng/g
— CB	ND		ND	ng/g
— CP	11		11	ng/g
— PAH	161		78	ng/g
TRACE METALS				
— Sb	0.4	45	8.9	µg/g
— As	8	8.7	12	µg/g
— Cd	7	11	7.0	µg/g
— Cr	232	337	307	µg/g
— Cu	2,781	1,540	606	µg/g
— Pb	1,601	7,712	949	µg/g
— Hg	0.103	1.8	0.019	µg/g
— Ni	172	337	396	µg/g
— Zn	1,200	4,205	1,519	µg/g

Appendix A-6.

COMBUSTION SYSTEM SUMMARY

HIGH LOAD / GOOD OPERATING CONDITIONS

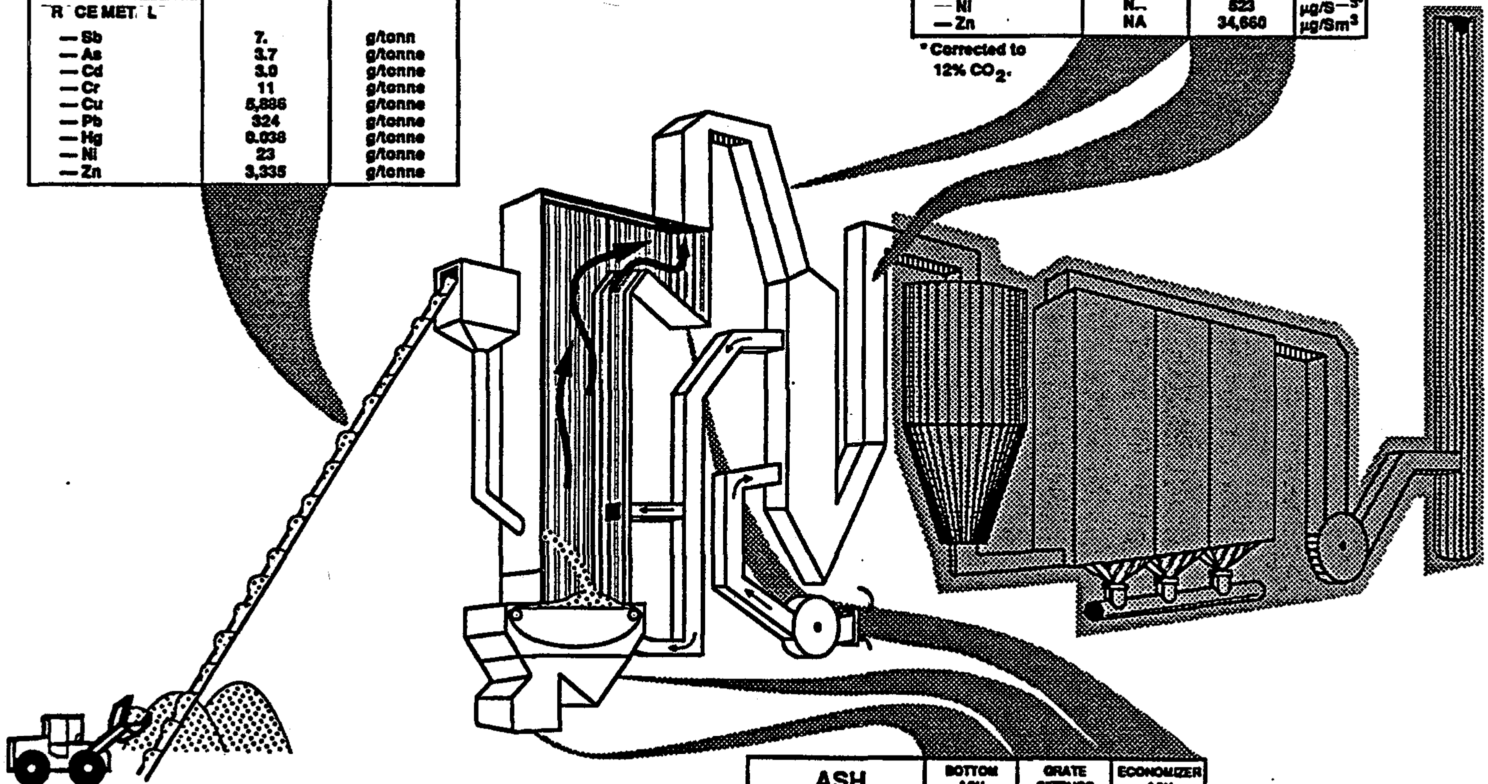
PT 12

COMBUSTION SYSTEM OPERATING CONDITIONS		
STEAM FLOW	235	klb/h
TEMPERATURE		
— Furnace	1,049	°C
— Boiler Inlet	607	°C
— Economizer Outlet	387	°C
— Air Heater Outlet	197	°C
UNDERGRATE : OVERFIRE AIR RATIO	47:53	%
EFFICIENCY		
— Output/Input	62.73	%

REFUSE DERIVED FUEL		
FEED RATE	27,964	kg/h
MOISTURE	20.0	%, wet, as fired
HHV	6,615	Btu/lb, wet
TRACE ORGANICS		
— PCDD	4.8	mg/tonne
— PCDF	0.11	mg/tonne
— PCB	188	mg/tonne
— CB	53	mg/tonne
— CP	558	mg/tonne
— PAH	11,169	mg/tonne
TRACE METALS		
— Sb	7.	g/tonne
— As	3.7	g/tonne
— Cd	3.0	g/tonne
— Cr	11	g/tonne
— Cu	5,896	g/tonne
— Pb	324	g/tonne
— Hg	0.036	g/tonne
— Ni	23	g/tonne
— Zn	3,335	g/tonne

FLUE GAS	PREHEATER INLET	SPRAY DRYER INLET	
GAS			
— FLOW	NA	143,620	Sm³/h
— TEMPERATURE	NA	201	°C
— MOISTURE	NA	16.3	%
CONTINUOUS MONITORS			
— O_2	NA	6.4	%
— CO_2	NA	12.9	%
— CO	NA	105	ppm
— NO_x	NA	180	ppm
— SO_2	NA	198	ppm
— HCl	NA	470	ppm
— THC	NA	6.1	ppm
TRACE ORGANICS			
— PCDD	NA	67	ng/Sm^{3*}
— PCDF	NA	215	ng/Sm^{3*}
— PCB	NA	34	ng/Sm^{3*}
— CB	NA	6,027	ng/Sm^{3*}
— CP	NA	16,636	ng/Sm^{3*}
— PAH	NA	16,208	ng/Sm^{3*}
PARTICULATE	NA	3,393.05	mg/Sm^{3*}
TRACE METALS			
— Sb	NA	173	µg/Sm^{3*}
— As	NA	247	µg/Sm^{3*}
— Cd	NA	562	µg/Sm^{3*}
— Cr	NA	745	µg/Sm^{3*}
— Cu	NA	1,112	µg/Sm^{3*}
— Pb	NA	4,036	µg/Sm^{3*}
— Hg	NA	558	µg/Sm^{3*}
— Ni	NA	523	µg/Sm^{3*}
— Zn	NA	34,660	µg/Sm^{3}

* Corrected to 12% CO_2.



ASH	BOTTOM ASH	GRATE SIFTINGS	ECONOMIZER ASH	
ASH RATE (dry)	3,280	106	17.0	kg/h
TRACE ORGANICS				
— PCDD	ND		ND	ng/g
— PCDF	ND		0.11	ng/g
— PCB	ND		ND	ng/g
— CB	ND		ND	ng/g
— CP	ND		10	ng/g
— PAH	196		ND	ng/g
TRACE METALS				
— Sb	2.1	23	2.7	µg/g
— As	14	13	12	µg/g
— Cd	4	13	8.9	µg/g
— Cr	189	192	210	µg/g
— Cu	16,067	1,616	580	µg/g
— Pb	1,289	8,558	979	µg/g
— Hg	0.026	0.76	ND	µg/g
— Ni	172	253	260	µg/g
— Zn	1,100	1,930	1,349	µg/g

Appendix A-7.

COMBUSTION SYSTEM SUMMARY

HIGH LOAD / POOR OPERATING CONDITIONS

PT 06

COMBUSTION SYSTEM OPERATING CONDITIONS

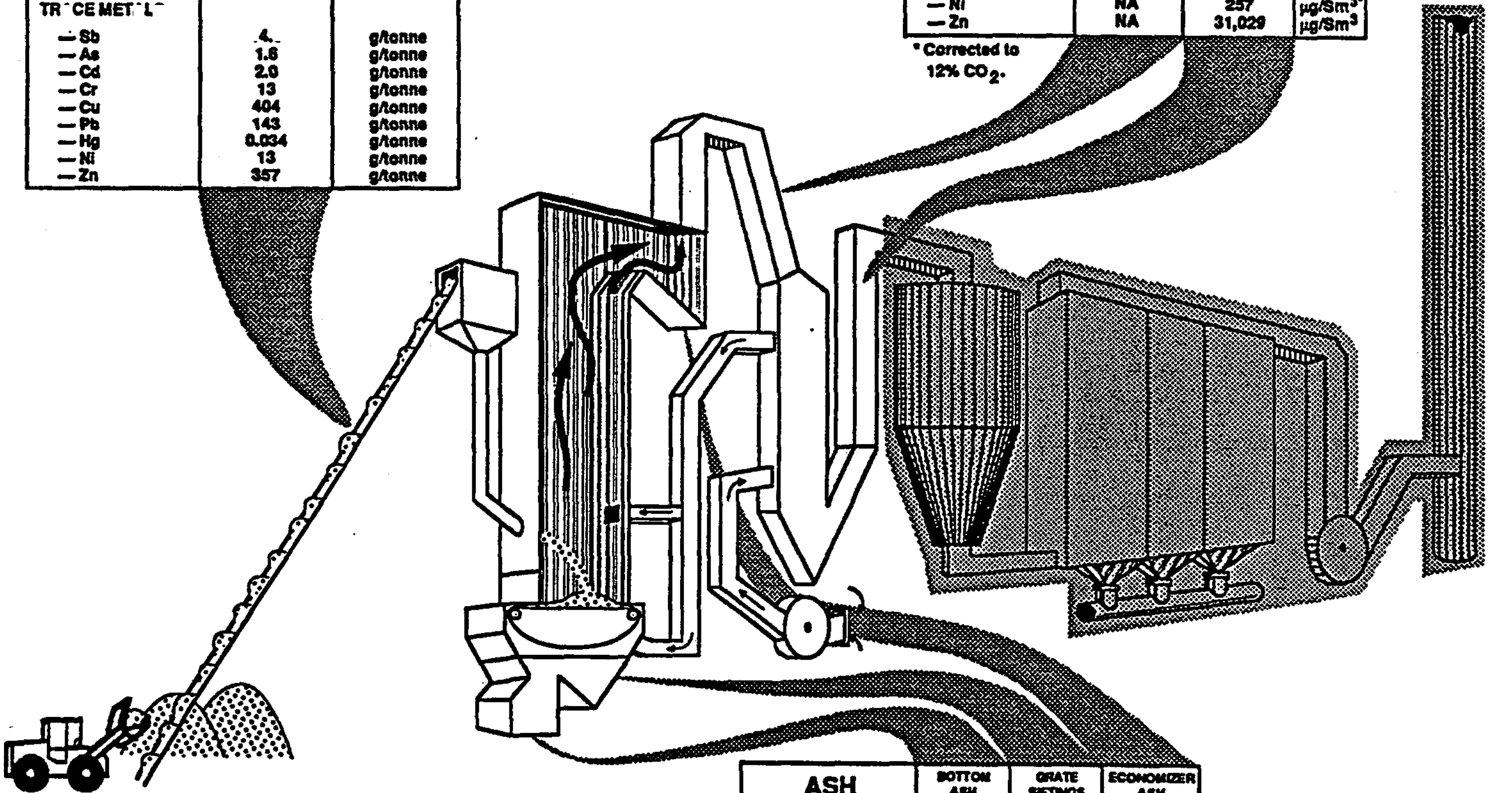
STEAM FLOW	234	klb/h
TEMPERATURE		
— Furnace	976	°C
— Boiler Inlet	612	°C
— Economizer Outlet	365	°C
— Air Heater Outlet	185	°C
UNDERGRATE : OVERFIRE AIR RATIO	43:57	%
EFFICIENCY		
— Output/Input	62.97	%

REFUSE DERIVED FUEL

FEED RATE	27,511	kg/h
MOISTURE	17.2	%, wet, as fired
HHV	6,991	Btu/lb, wet
TRACE ORGANICS		
— PCDD	13	mg/tonne
— PCDF	0.15	mg/tonne
— PCB	ND	mg/tonne
— CB	ND	mg/tonne
— CP	2,278	mg/tonne
— PAH	8,263	mg/tonne
TRACE METALS		
— Sb	4.	g/tonne
— As	1.6	g/tonne
— Cd	2.0	g/tonne
— Cr	13	g/tonne
— Cu	404	g/tonne
— Pb	143	g/tonne
— Hg	0.034	g/tonne
— Ni	13	g/tonne
— Zn	357	g/tonne

FLUE GAS	PREHEATER INLET	SPRAY DRYER INLET	
GAS			
— FLOW	NA	161,062	Sm^3/h
— TEMPERATURE	NA	185	°C
— MOISTURE	NA	14.0	%
CONTINUOUS MONITORS			
— O_2	NA	7.9	%
— CO_2	NA	11.5	%
— CO	NA	397	ppm
— NO_x	NA	157	ppm
— SO_2	NA	192	ppm
— HCl	NA	404	ppm
— THC	NA	28.6	ppm
TRACE ORGANICS			
— PCDD	NA	317	ng/Sm^{3*}
— PCDF	NA	885	ng/Sm^{3*}
— PCB	NA	12	ng/Sm^{3*}
— CB	NA	9,403	ng/Sm^{3*}
— CP	NA	41,588	ng/Sm^{3*}
— PAH	NA	88,626	ng/Sm^{3*}
PARTICULATE	NA	3,308.09	mg/Sm^{3*}
TRACE METALS			
— Sb	NA	51	μg/Sm^{3*}
— As	NA	194	μg/Sm^{3*}
— Cd	NA	437	μg/Sm^{3*}
— Cr	NA	353	μg/Sm^{3*}
— Cu	NA	1,264	μg/Sm^{3*}
— Pb	NA	7,229	μg/Sm^{3*}
— Hg	NA	583	μg/Sm^{3*}
— Ni	NA	257	μg/Sm^{3*}
— Zn	NA	31,029	μg/Sm^3

* Corrected to 12% CO_2.



ASH	BOTTOM ASH	GRATE SIFTINGS	ECONOMIZER ASH	
ASH RATE (dry)	3,352	71	10.6	kg/h
TRACE ORGANICS				
— PCDD	ND		0.03	ng/g
— PCDF	ND		1.2	ng/g
— PCB	ND		ND	ng/g
— CB	ND		ND	ng/g
— CP	14		4.0	ng/g
— PAH	136		1,087	ng/g
TRACE METALS				
— Sb	ND	44	9.3	μg/g
— As	7.8	9.4	18	μg/g
— Cd	4.6	12	6.2	μg/g
— Cr	158	284	150	μg/g
— Cu	1,121	11,534	509	μg/g
— Pb	1,016	16,829	659	μg/g
— Hg	0.32	1.0	0.024	μg/g
— Ni	96	303	170	μg/g
— Zn	1,261	2,798	1,758	μg/g

APPENDIX B

AIR POLLUTION CONTROL SYSTEM SUMMARY BY PERFORMANCE TEST CONDITION

AIR POLLUTION CONTROL SYSTEM SUMMARY

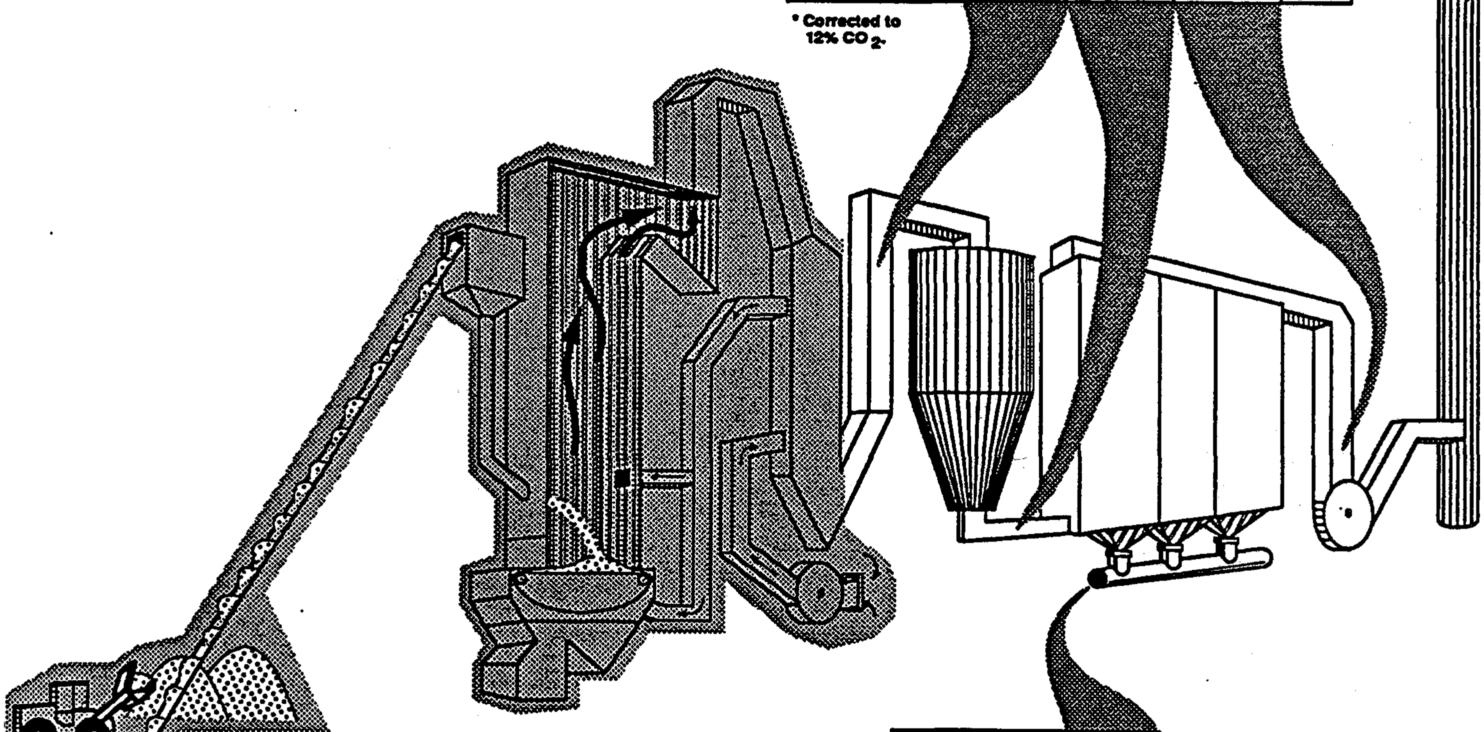
LOW FFO SO_2 /LOW SDO TEPERATURE

PT 07

APC SYSTEM OPERATING CONDITIONS			
RUN		PT07	
FFO SO_2 SET POINT		LOW	
SDO TEMP. SET POINT		120	°C

FLUE GAS	SPRAY DRYER INLET	SPRAY DRYER OUTLET	FABRIC FILTER OUTLET	
GAS				
— FLOW	158,054	NA	172,766	Sm^3/h
— TEMPERATURE	201	124	106	°C
— MOISTURE	15.7	NA	18.9	%
CONTINUOUS MONITORS				
— O_2	7.2	NA	9.4	%
— CO_2	12.1	11.1	10.4	%
— CO	338	NA	411	ppm
— NO_x	172	NA	NA	ppm
— SO_2	183	127	17	ppm
— HCl	399	10	8	ppm
— THC	13.3	NA	12.4	ppm
TRACE ORGANICS				
— PCDD	207	NA	0.167	ng/Sm^{3*}
— PCDF	796	NA	0.145	ng/Sm^{3*}
— PCB	17	NA	ND	ng/Sm^{3*}
— CB	7,074	NA	108	ng/Sm^{3*}
— CP	25,168	NA	226	ng/Sm^{3*}
— PAH	51,774	NA	1,390	ng/Sm^{3*}
PARTICULATE	4,229.9	NA	4.39	mg/Sm^{3*}
TRACE METALS				
— Sb	55	NA	ND	$\mu g/Sm^{3*}$
— As	176	NA	ND	$\mu g/Sm^{3*}$
— Cd	515	NA	ND	$\mu g/Sm^{3*}$
— Cr	520	NA	8.4	$\mu g/Sm^{3*}$
— Cu	1,428	NA	ND	$\mu g/Sm^{3*}$
— Pb	5,877	NA	29	$\mu g/Sm^{3*}$
— Hg	584	NA	7.4	$\mu g/Sm^{3*}$
— Ni	427	NA	6.0	$/Sm^{3*}$
— Zn	34,312	NA	ND	$\mu g/Sm^3$

* Corrected to 12% CO_2.



ASH	FABRIC FILTER ASH	
ASH RATE (dry)	550	kg/h
TRACE ORGANICS		
— PCDD	154	ng/g
— PCDF	271	ng/g
— PCB	ND	ng/g
— CB	941	ng/g
— CP	4,997	ng/g
— PAH	1,992	ng/g
TRACE METALS		
— Sb	9.3	µg/g
— As	17	µg/g
— Cd	90	µg/g
— Cr	147	µg/g
— Cu	323	µg/g
— Pb	3,051	µg/g
— Hg	37	µg/g
— Ni	249	µg/g
— Zn	9,200	µg/g

Appendix B-2.

AIR POLLUTION CONTROL SYSTEM SUMMARY

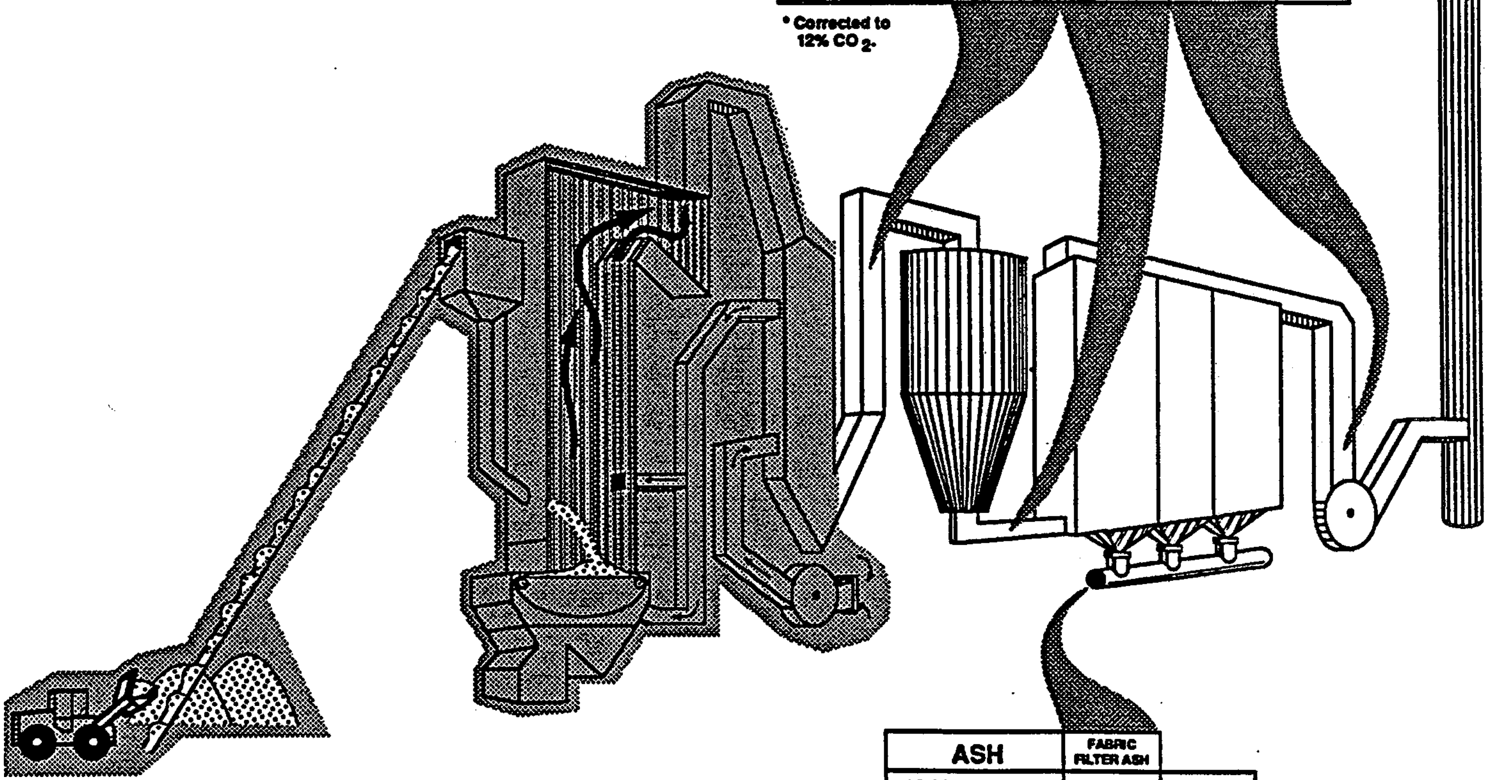
MEDIUM FFO SO_2 /LOW SDO TEMPERATURE

PT 10

APC SYSTEM OPERATING CONDITIONS			
RUN		PT10	
FFO SO_2 SET POINT		MEDIUM	
SDO TEMP. SET POINT		120	°C

FLUE GAS	SPRAY DRYER INLET	SPRAY DRYER OUTLET	FABRIC FILTER OUTLET	
GAS				
— FLOW	158,976	NA	167,398	Sm^3/h
— TEMPERATURE	193	123	106	°C
— MOISTURE	13.8	NA	15.4	%
CONTINUOUS MONITORS				
— O_2	9.2	NA	10.9	%
— CO_2	10.5	9.6	9.1	%
— CO	77	NA	39	ppm
— NO_x	186	NA	NA	ppm
— SO_2	194	131	74	ppm
— HCl	429	15	19	ppm
— THC	1.6	NA	1.9	ppm
TRACE ORGANICS				
— PCDD	243	NA	0.181	ng/Sm^{3*}
— PCDF	424	NA	0.103	ng/Sm^{3*}
— PCB	13	NA	ND	ng/Sm^{3*}
— CB	6,170	NA	42	ng/Sm^{3*}
— CP	16,198	NA	79	ng/Sm^{3*}
— PAH	6,289	NA	2,603	ng/Sm^{3*}
PARTICULATE	4,531.2	NA	4.09	mg/Sm^{3*}
TRACE METALS				
— Sb	156	NA	ND	µg/Sm^{3*}
— As	210	NA	ND	µg/Sm^{3*}
— Cd	599	NA	ND	µg/Sm^{3*}
— Cr	871	NA	9.4	µg/Sm^{3*}
— Cu	1,849	NA	ND	µg/Sm^{3*}
— Pb	4,770	NA	43	µg/Sm^{3*}
— Hg	718	NA	8.4	µg/Sm^{3*}
— Ni	608	NA	2.2	µg/Sm^{3*}
— Zn	48,469	NA	ND	µg/Sm^3

* Corrected to 12% CO_2.



ASH	FABRIC FILTER ASH	
ASH RATE (dry)	1,166	kg/h
TRACE ORGANICS		
— PCDD	27	ng/g
— PCDF	47	ng/g
— PCB	ND	ng/g
— CB	684	ng/g
— CP	1,924	ng/g
— PAH	1,402	ng/g
TRACE METALS		
— Sb	10	µg/g
— As	19	µg/g
— Cd	87	µg/g
— Cr	274	µg/g
— Cu	637	µg/g
— Pb	2,352	µg/g
— Hg	27	µg/g
— Ni	304	µg/g
— Zn	5,879	µg/g

Appendix B-3.

AIR POLLUTION CONTROL SYSTEM SUMMARY

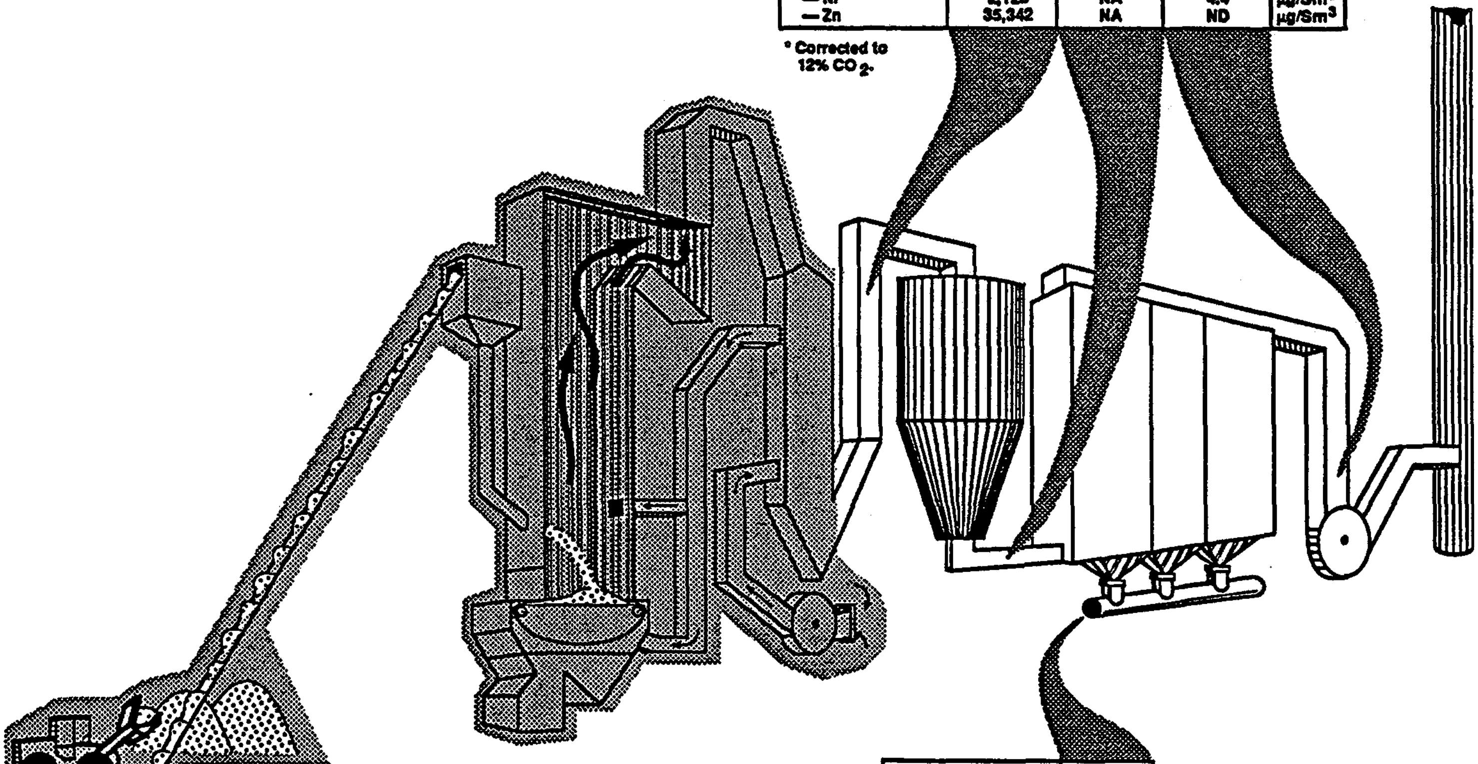
HIGH FFO SO_2 /LOW SDO TEMPERATURE

PT 02/05

APC SYSTEM OPERATING CONDITIONS			
RUN	PT02	PT05	
FFO SO_2 SET POINT	HIGH	HIGH	
SDO TEMP. SET POINT	120	120	°C

FLUE GAS	SPRAY DRYER INLET	SPRAY DRYER OUTLET	FABRIC FILTER OUTLET	
GAS				
— FLOW	149,940	NA	159,958	Sm^3/h
— TEMPERATURE	191	122	106	°C
— MOISTURE	13.8	NA	15.7	%
CONTINUOUS MONITORS				
— O_2	8.9	NA	10.6	%
— CO_2	10.7	9.6	9.4	%
— CO	321	NA	508	ppm
— NO_x	166	NA	NA	ppm
— SO_2	173	NA	112	ppm
— HCl	470	50	20	ppm
— THC	28.7	NA	18.5	ppm
TRACE ORGANICS				
— PCDD	396	NA	0.225	ng/Sm^3*
— PCDF	1,007	NA	0.622	ng/Sm^3*
— PCB	23	NA	ND	ng/Sm^3*
— CB	10,860	NA	409	ng/Sm^3*
— CP	62,938	NA	1,645	ng/Sm^3*
— PAH	60,176	NA	4,844	ng/Sm^3*
PARTICULATE	4,949	NA	4.82	mg/Sm^3*
TRACE METALS				
— Sb	103	NA	ND	µg/Sm^3*
— As	250	NA	ND	µg/Sm^3*
— Cd	547	NA	ND	µg/Sm^3*
— Cr	859	NA	15.1	µg/Sm^3*
— Cu	1,781	NA	ND	µg/Sm^3*
— Pb	13,472	NA	46.2	µg/Sm^3*
— Hg	680	NA	6.6	µg/Sm^3*
— Ni	2,128	NA	4.4	µg/Sm^3*
— Zn	35,342	NA	ND	µg/Sm^3

* Corrected to 12% CO_2.



ASH	FABRIC* FILTER ASH	
ASH RATE (dry)	429	kg/h
TRACE ORGANICS		
— PCDD	96	ng/g
— PCDF	71	ng/g
— PCB	ND	ng/g
— CB	1,085	ng/g
— CP	2,870	ng/g
— PAH	9,437	ng/g
TRACE METALS		
— Sb	9.0	µg/g
— As	15	µg/g
— Cd	70	µg/g
— Cr	264	µg/g
— Cu	431	µg/g
— Pb	1,967	µg/g
— Hg	25	µg/g
— Ni	744	µg/g
— Zn	5,463	µg/g

* PT 05 only

Appendix B-4.

AIR POLLUTION CONTROL SYSTEM SUMMARY

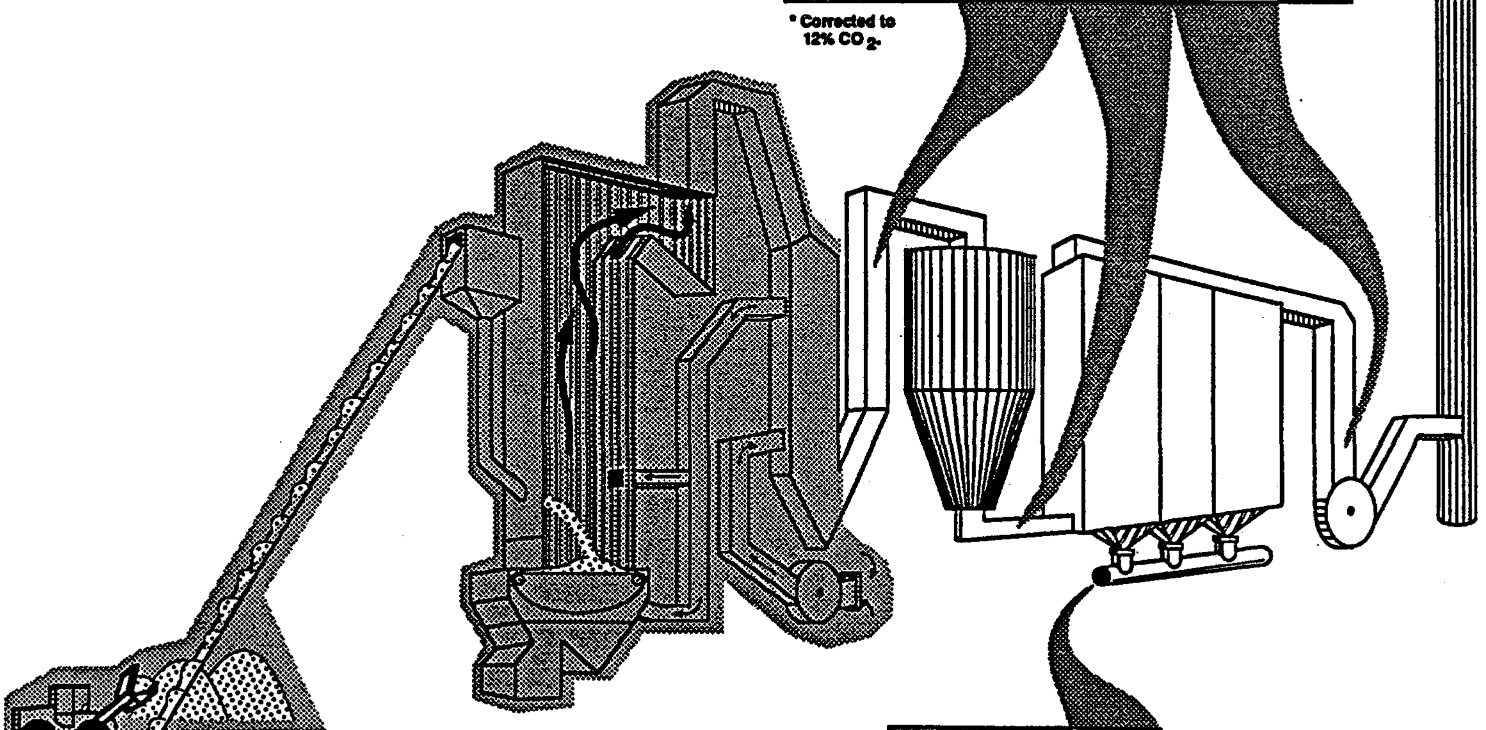
LOW FFO SO_2 /MEDIUM SDO TEMPERATURE

PT 06

APC SYSTEM OPERATING CONDITIONS			
RUN	PT06		
FFO SO_2 SET POINT	LOW		
SDO TEMP. SET POINT	190		°C

FLUE GAS	SPRAY DRYER INLET	SPRAY DRYER OUTLET	FABRIC FILTER OUTLET	
GAS				
— FLOW	161,062	NA	172,107	Sm^3/h
— TEMPERATURE	185	141	123	°C
— MOISTURE	14.0	NA	15.5	%
CONTINUOUS MONITORS				
— O_2	7.9	NA	9.8	%
— CO_2	11.5	10.8	10.2	%
— CO	397	NA	NA	ppm
— NO_x	157	NA	NA	ppm
— SO_2	192	108	9	ppm
— HCl	404	20	10	ppm
— THC	28.6	NA	26.1	ppm
TRACE ORGANICS				
— PCDD	317	NA	0.346	ng/Sm^{3*}
— PCDF	885	NA	0.162	ng/Sm^{3*}
— PCB	12	NA	ND	ng/Sm^{3*}
— CB	9,403	NA	539	ng/Sm^{3*}
— CP	41,588	NA	1,282	ng/Sm^{3*}
— PAH	88,626	NA	2,034	ng/Sm^{3*}
PARTICULATE	3,308.1	NA	2.68	mg/Sm^{3*}
TRACE METALS				
— Sb	51	NA	ND	$\mu g/Sm^{3*}$
— As	194	NA	ND	$\mu g/Sm^{3*}$
— Cd	437	NA	ND	$\mu g/Sm^{3*}$
— Cr	353	NA	7.6	$\mu g/Sm^{3*}$
— Cu	1,264	NA	ND	$\mu g/Sm^{3*}$
— Pb	7,229	NA	37	$\mu g/Sm^{3*}$
— Hg	583	NA	11.5	$\mu g/Sm^{3*}$
— Ni	257	NA	3.8	$\mu g/Sm^{3*}$
— Zn	31,029	NA	ND	$\mu g/Sm^3$

* Corrected to 12% CO_2.



ASH	FABRIC FILTER ASH	
ASH RATE (dry)	1,239	kg/h
TRACE ORGANICS		
— PCDD	227	ng/g
— PCDF	282	ng/g
— PCB	ND	ng/g
— CB	1,684	ng/g
— CP	6,095	ng/g
— PAH	7,431	ng/g
TRACE METALS		
— Sb	10	µg/g
— As	19	µg/g
— Cd	96	µg/g
— Cr	154	µg/g
— Cu	374	µg/g
— Pb	3,666	µg/g
— Hg	36	µg/g
— Ni	374	µg/g
— Zn	9,769	µg/g

Appendix B-5.

AIR POLLUTION CONTROL SYSTEM SUMMARY

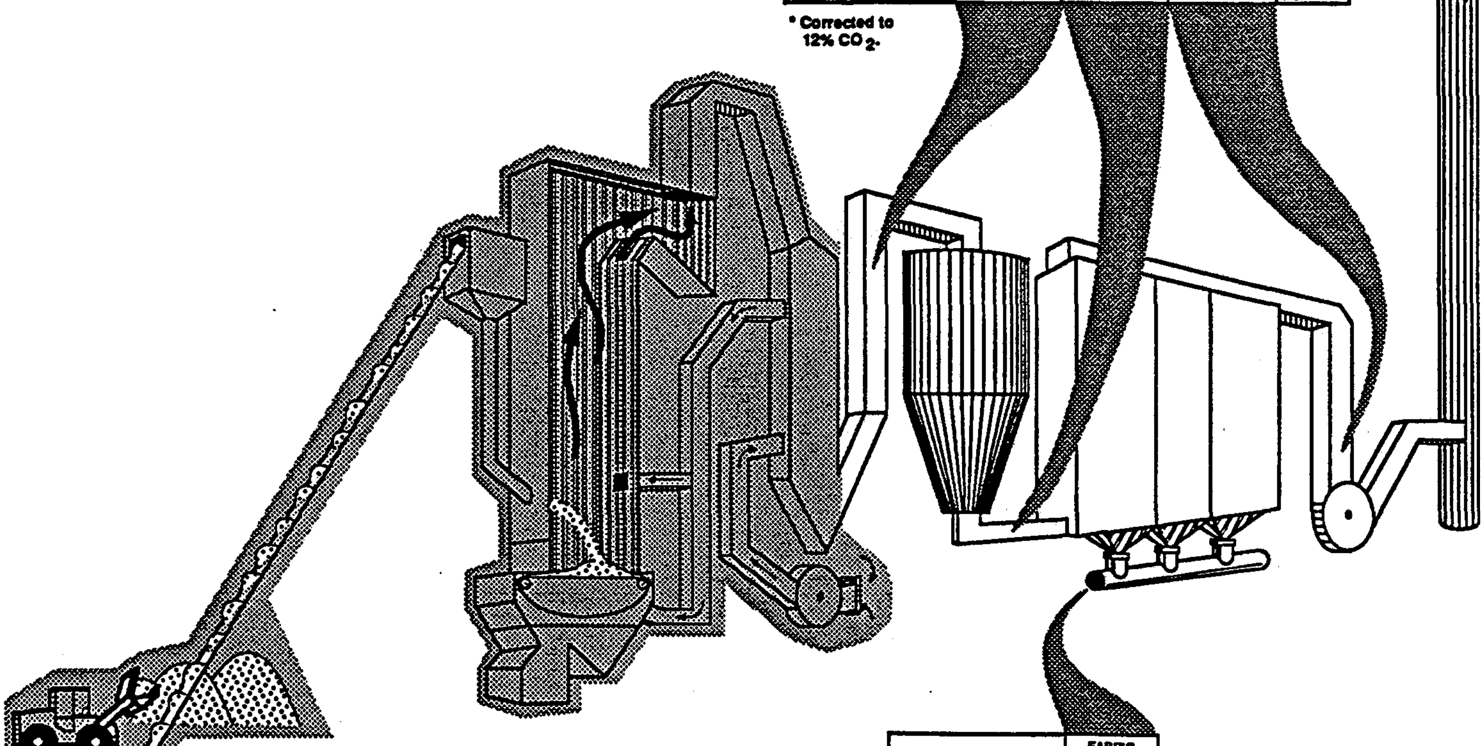
MEDIUM FFO SO_2 /MEDIUM SDO TEMPERATURE

PT 12/13/14

APC SYSTEM OPERATING CONDITIONS				
RUN	PT 12	PT 13	PT 14	
FFO SO_2 SET POINT	MEDIUM	MEDIUM	MEDIUM	
SDO TEMP. SET POINT	190	190	190	°C

FLUE GAS	SPRAY DRYER INLET	SPRAY DRYER OUTLET	FABRIC FILTER OUTLET	
GAS				
— FLOW	136,789	NA	155,124	Sm^3/h
— TEMPERATURE	194	140	117	°C
— MOISTURE	13.6	NA	14.5	%
CONTINUOUS MONITORS				
— O_2	8.7	NA	10.7	%
— CO_2	11.0	10.2	9.5	%
— CO	111	NA	201	ppm
— NO_x	171	NA	NA	ppm
— SO_2	187	136	89	ppm
— HCl	445	32	18	ppm
— THC	5.2	NA	3.0	ppm
TRACE ORGANICS				
— PCDD	95	NA	0.062	ng/Sm^{3*}
— PCDF	341	NA	0.122	ng/Sm^{3*}
— PCB	ND	NA	ND	ng/Sm^{3*}
— CB	4,647	NA	ND	ng/Sm^{3*}
— CP	14,419	NA	87	ng/Sm^{3*}
— PAH	7,747	NA	2,852	ng/Sm^{3*}
PARTICULATE	3,433	NA	5.46	mg/Sm^{3*}
TRACE METALS				
— Sb	133	NA	ND	$\mu g/Sm^{3*}$
— As	219	NA	ND	$\mu g/Sm^{3*}$
— Cd	569	NA	ND	$\mu g/Sm^{3*}$
— Cr	948	NA	17.2	$\mu g/Sm^{3*}$
— Cu	1,711	NA	ND	$\mu g/Sm^{3*}$
— Pb	8,563	NA	43	$\mu g/Sm^{3*}$
— Hg	668	NA	9.2	$\mu g/Sm^{3*}$
— Ni	2,428	NA	22.9	$\mu g/Sm^{3*}$
— Zn	43,733	NA	ND	$\mu g/Sm^{3}$

* Corrected to 12% CO_2.



ASH	FABRIC FILTER ASH	
ASH RATE (dry)	724	kg/h
TRACE ORGANICS		
— PCDD	102	ng/g
— PCDF	111	ng/g
— PCB	ND	ng/g
— CB	1,218	ng/g
— CP	1,832	ng/g
— PAH	4,093	ng/g
TRACE METALS		
— Sb	12.8	µg/g
— As	19	µg/g
— Cd	118	µg/g
— Cr	207	µg/g
— Cu	483	µg/g
— Pb	2,812	µg/g
— Hg	39	µg/g
— Ni	394	µg/g
— Zn	6,339	µg/g

Appendix B-6.

AIR POLLUTION CONTROL SYSTEM SUMMARY

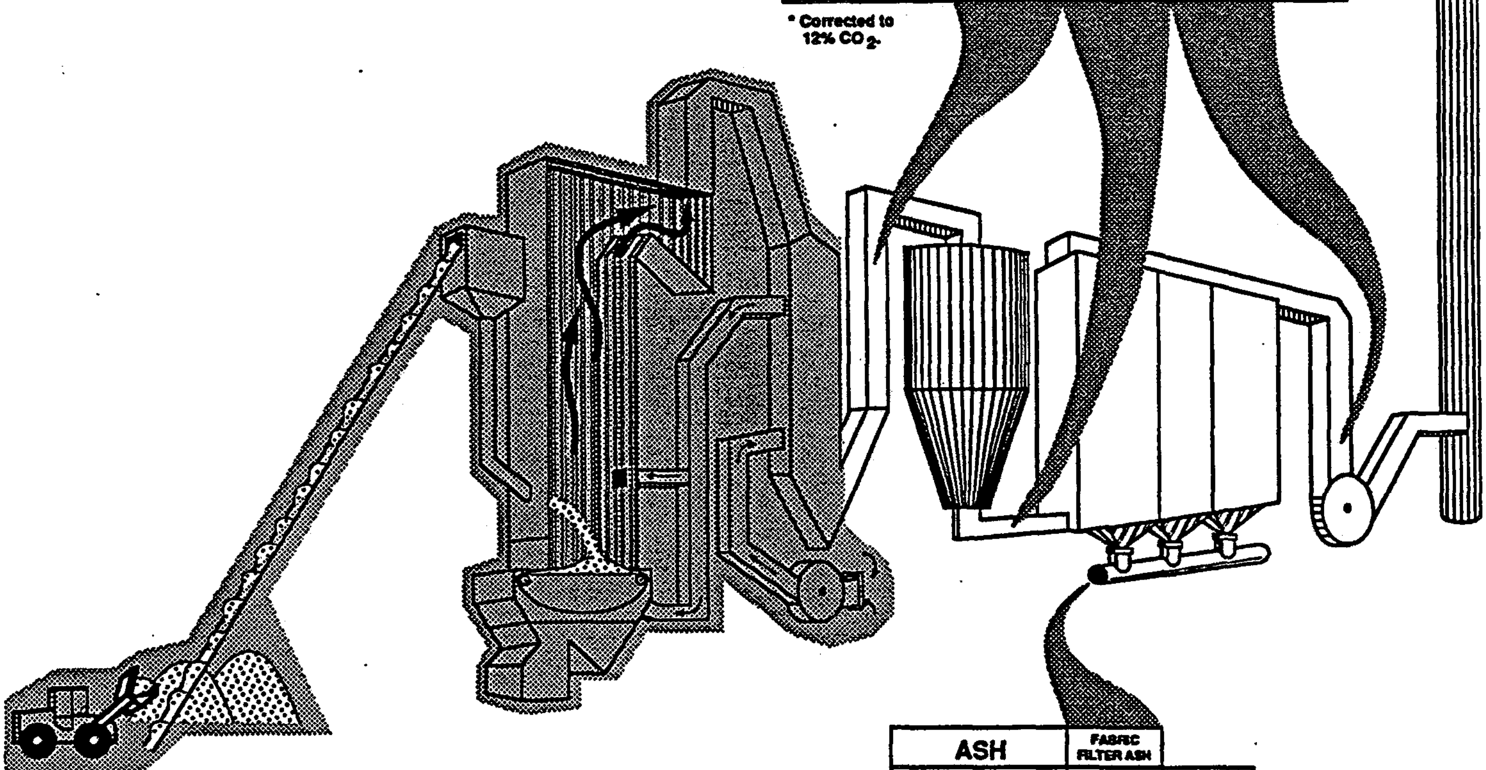
HIGH FFO SO_2 /MEDIUM SDO TEMPERATURE

PT 08

APC SYSTEM OPERATING CONDITIONS			
RUN	PT08		
FFO SO_2 SET POINT	HIGH		
SDO TEMP. SET POINT	190		°C

FLUE GAS	SPRAY DRYER INLET	SPRAY DRYER OUTLET	FABRIC FILTER OUTLET	
GAS				
— FLOW	150,203	NA	164,013	Sm^3/h
— TEMPERATURE	199	142	118	°C
— MOISTURE	16.3	NA	18.0	%
CONTINUOUS MONITORS				
— O_2	7.5	NA	9.6	%
— CO_2	11.8	11	10.4	%
— CO	89	NA	35	ppm
— NO_x	193	NA	NA	ppm
— SO_2	184	164	126	ppm
— HCl	538	44	41	ppm
— THC	3.0	NA	1.6	ppm
TRACE ORGANICS				
— PCDD	211	NA	0.286	ng/Sm^{3*}
— PCDF	951	NA	0.467	ng/Sm^{3*}
— PCB	24	NA	7	ng/Sm^{3*}
— CB	7,071	NA	112	ng/Sm^{3*}
— CP	20,226	NA	190	ng/Sm^{3*}
— PAH	10,259	NA	2,386	ng/Sm^{3*}
PARTICULATE	4,745.4	NA	3.88	mg/Sm^{3*}
TRACE METALS				
— Sb	133	NA	ND	$\mu g/Sm^{3*}$
— As	224	NA	ND	$\mu g/Sm^{3*}$
— Cd	832	NA	ND	$\mu g/Sm^{3*}$
— Cr	862	NA	31.4	$\mu g/Sm^{3*}$
— Cu	2,436	NA	ND	$\mu g/Sm^{3*}$
— Pb	4,649	NA	40	$\mu g/Sm^{3*}$
— Hg	646	NA	4.2	$\mu g/Sm^{3*}$
— Ni	406	NA	66.7	$\mu g/Sm^{3*}$
— Zn	43,550	NA	ND	$\mu g/Sm^3$

* Corrected to 12% CO_2.



ASH	FABRIC FILTER ASH	
ASH RATE (dry)	434	kg/h
TRACE ORGANICS		
— PCDD	62	ng/g
— PCDF	96	ng/g
— PCB	ND	ng/g
— CB	729	ng/g
— CP	1,636	ng/g
— PAH	2,905	ng/g
TRACE METALS		
— Sb	12.7	µg/g
— As	22	µg/g
— Cd	62	µg/g
— Cr	210	µg/g
— Cu	717	µg/g
— Pb	2,439	µg/g
— Hg	25	µg/g
— Ni	392	µg/g
— Zn	5,738	µg/g

Appendix B-7.

AIR POLLUTION CONTROL SYSTEM SUMMARY

LOW FFO SO_2/HIGH SDO TEMPERATURE

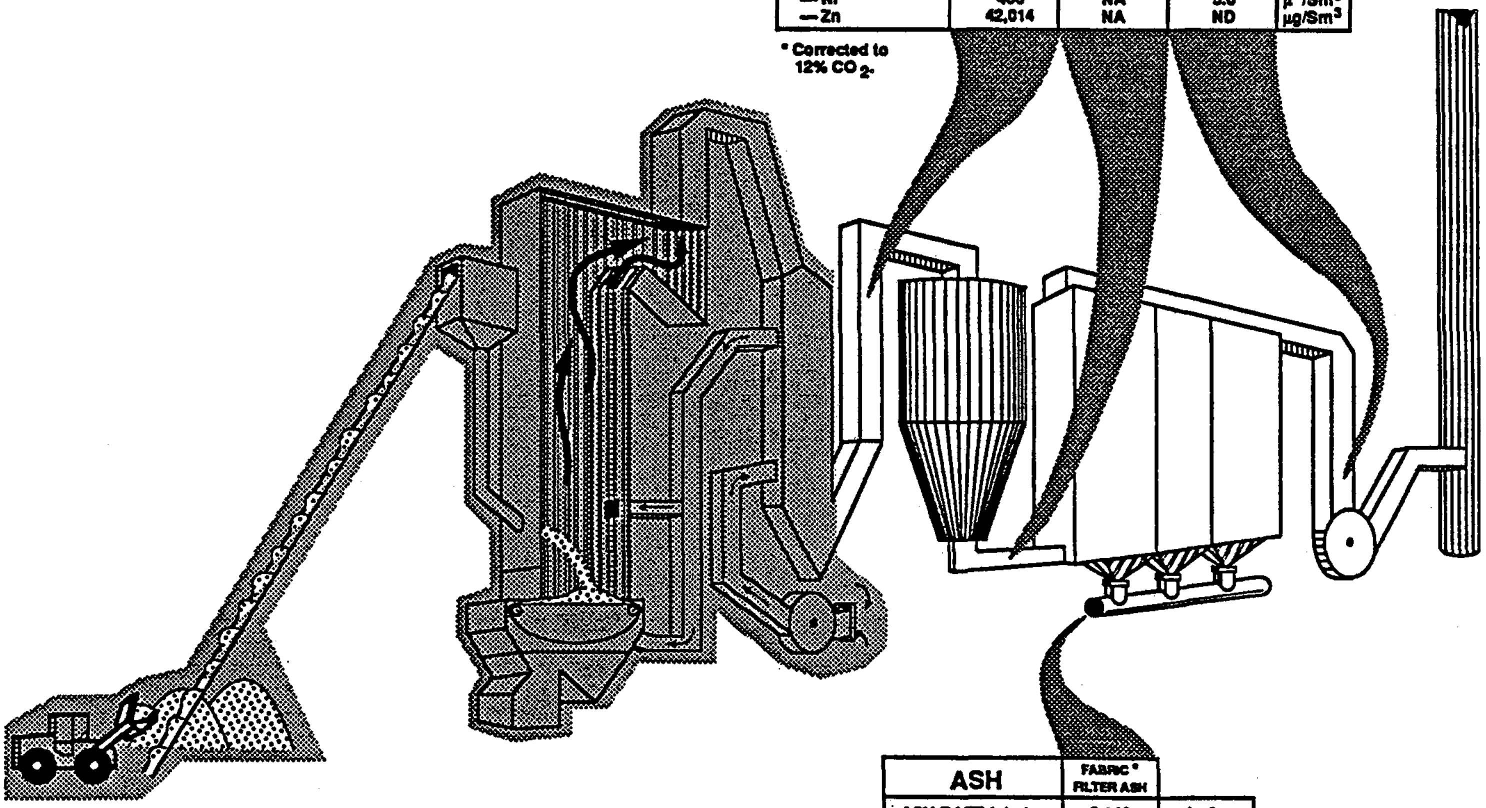
PT 03/11

APC SYSTEM OPERATING CONDITIONS

RUN	PT03	PT11	
FFO SO_2 SET POINT	LOW	LOW	
SDO TEMP. SET POINT	165	165	°C

FLUE GAS	SPRAY DRYER INLET	SPRAY DRYER OUTLET	FABRIC FILTER OUTLET	
GAS				
— FLOW	147,186	NA	161,525	Sm³/h
— TEMPERATURE	199	165	140	°C
— MOISTURE	16.1	NA	15.2	%
CONTINUOUS MONITORS				
— O_2	7.4	NA	9.5	%
— CO_2	11.8	11.0	10.5	%
— CO	219	NA	249	ppm
— NO_x	168	NA	NA	ppm
— SO_2	187	107	17	ppm
— HCl	416	15	21	ppm
— THC	10.8	NA	8.6	ppm
TRACE ORGANICS				
— PCDD	161	NA	0.347	ng/Sm³*
— PCDF	611	NA	0.285	ng/Sm³*
— PCB	42	NA	27	ng/Sm³*
— CB	6,159	NA	294	ng/Sm³*
— CP	20,798	NA	192	ng/Sm³*
— PAH	47,066	NA	3,686	ng/Sm³*
PARTICULATE	4,313	NA	5.60	mg/Sm³*
TRACE METALS				
— Sb	79	NA	ND	µg/Sm³*
— As	214	NA	ND	µg/Sm³*
— Cd	694	NA	ND	µg/Sm³*
— Cr	579	NA	8.3	µg/Sm³*
— Cu	1,908	NA	ND	µg/Sm³*
— Pb	11,479	NA	43	µg/Sm³*
— Hg	622	NA	19.6	µg/Sm³*
— Ni	466	NA	5.0	µ /Sm³*
— Zn	42,014	NA	ND	µg/Sm³

* Corrected to 12% CO_2.



ASH	FABRIC * FILTER ASH	
ASH RATE (dry)	2,140	kg/h
TRACE ORGANICS		
— PCDD	49	ng/g
— PCDF	100	ng/g
— PCB	ND	ng/g
— CB	704	ng/g
— CP	2,225	ng/g
— PAH	1,087	ng/g
TRACE METALS		
— Sb	10	µg/g
— As	18	µg/g
— Cd	97	µg/g
— Cr	240	µg/g
— Cu	679	µg/g
— Pb	2,405	µg/g
— Hg	30	µg/g
— Ni	439	µg/g
— Zn	6,687	µg/g

* PT 11 only

Appendix B-8.

AIR POLLUTION CONTROL SYSTEM SUMMARY

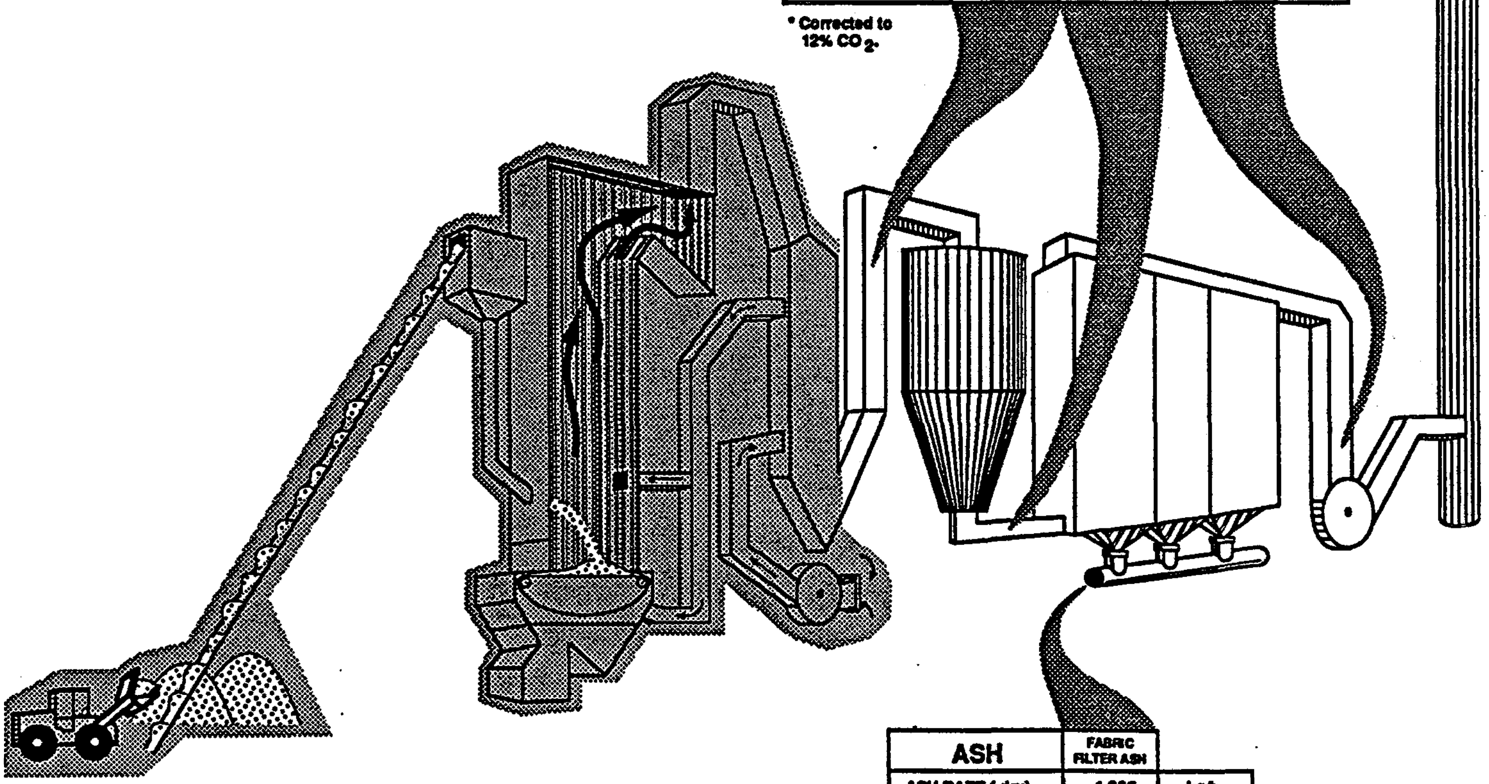
MEDIUM FFO SO_2 /HIGH SDO TEMPERATURE

PT 04

APC SYSTEM OPERATING CONDITIONS			
RUN	PT04		
FFO SO_2 SET POINT	MEDIUM		
SDO TEMP. SET POINT	165		°C

FLUE GAS	SPRAY DRYER INLET	SPRAY DRYER OUTLET	FABRIC FILTER OUTLET	
GAS				
—FLOW	154,509	NA	165,970	Sm^3/h
—TEMPERATURE	191	166	142	°C
—MOISTURE	14.6	NA	14.9	%
CONTINUOUS MONITORS				
—O_2	7.6	NA	9.3	%
—CO_2	11.9	11.0	11.0	%
—CO	214	NA	168	ppm
—NO_x	172	NA	NA	ppm
—SO_2	186	NA	44	ppm
—HCl	471	45	31	ppm
—THC	7.7	NA	5.1	ppm
TRACE ORGANICS				
—PCDD	151	NA	0.368	ng/Sm^{3*}
—PCDF	623	NA	0.486	ng/Sm^{3*}
—PCB	ND	NA	19	ng/Sm^{3*}
—CB	5,964	NA	93	ng/Sm^{3*}
—CP	16,964	NA	167	ng/Sm^{3*}
—PAH	22,519	NA	1,983	ng/Sm^{3*}
PARTICULATE	3,274.3	NA	7.62	mg/Sm^{3*}
TRACE METALS				
—Sb	80	NA	ND	$\mu g/Sm^{3*}$
—As	168	NA	ND	$\mu g/Sm^{3*}$
—Cd	536	NA	ND	$\mu g/Sm^{3*}$
—Cr	538	NA	10.0	$\mu g/Sm^{3*}$
—Cu	1,289	NA	ND	$\mu g/Sm^{3*}$
—Pb	10,050	NA	37	$\mu g/Sm^{3*}$
—Hg	614	NA	13.4	$\mu g/Sm^{3*}$
—Ni	586	NA	6.0	$\mu g/Sm^{3*}$
—Zn	31,654	NA	48	$\mu g/Sm^3$

* Corrected to 12% CO_2.



ASH	FABRIC FILTER ASH	
ASH RATE (dry)	1,385	kg/h
TRACE ORGANICS		
—PCDD	84	ng/g
—PCDF	172	ng/g
—PCB	ND	ng/g
—CB	1,059	ng/g
—CP	3,320	ng/g
—PAH	1,806	ng/g
TRACE METALS		
—Sb	8.6	µg/g
—As	20	µg/g
—Cd	96	µg/g
—Cr	179	µg/g
—Cu	388	µg/g
—Pb	3,413	µg/g
—Hg	48	µg/g
—Ni	229	µg/g
—Zn	6,467	µg/g

Appendix B-9.

AIR POLLUTION CONTROL SYSTEM SUMMARY

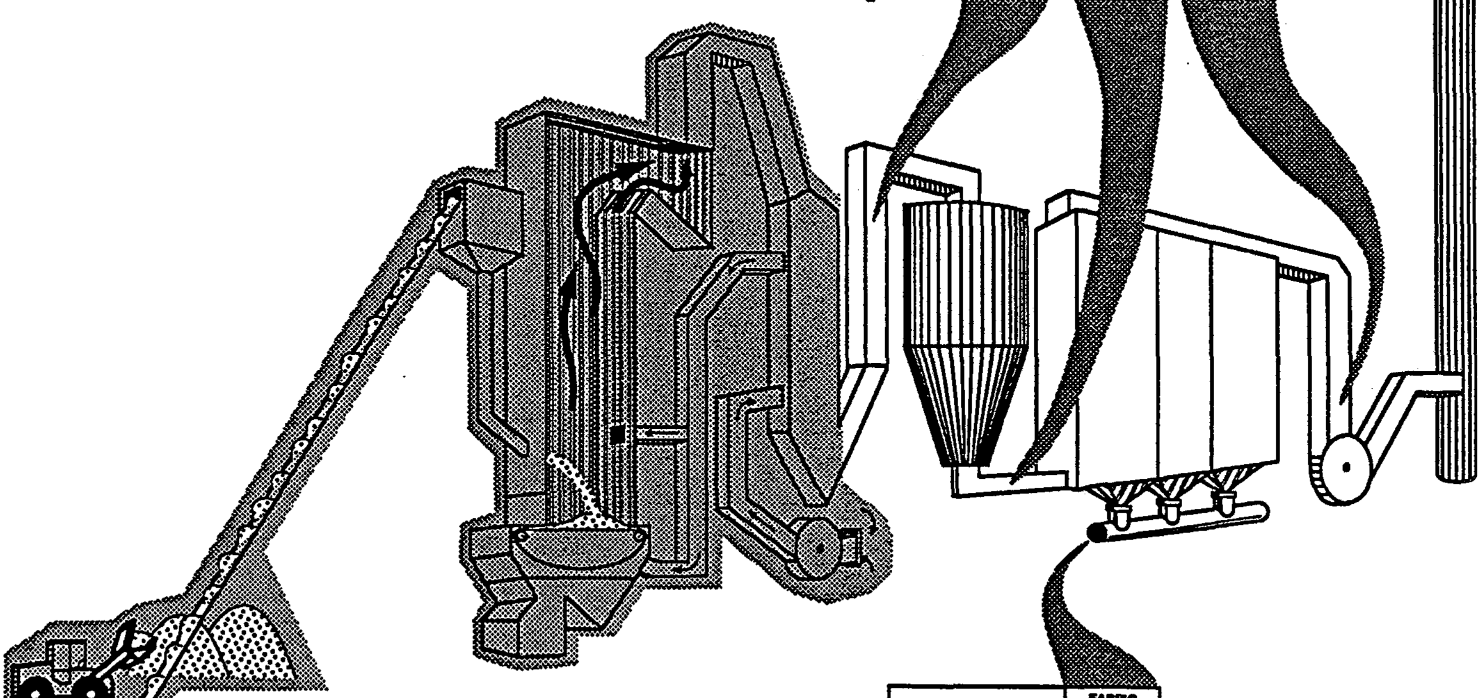
HIGH FFO SO_2 /HIGH SDO TEMPERATURE

PT 09

APC SYSTEM OPERATING CONDITIONS			
RUN	PT09		
FFO SO_2 SET POINT	HIGH		
SDO TEMP. SET POINT	165		°C

FLUE GAS	SPRAY DRYER INLET	SPRAY DRYER OUTLET	FABRIC FILTER OUTLET	
GAS				
— FLOW	146,255	NA	163,144	Sm^3/h
— TEMPERATURE	191	170	140	°C
— MOISTURE	17.5	NA	15.3	%
CONTINUOUS MONITORS				
— O_2	7.6	NA	9.7	%
— CO_2	11.9	11.1	10.4	%
— CO	92	NA	72	ppm
— NO_x	188	NA	NA	ppm
— SO_2	178	159	189	ppm
— HCl	432	146	98	ppm
— THC	5.4	NA	8.5	ppm
TRACE ORGANICS				
— PCDD	71	NA	0.582	ng/Sm^{3*}
— PCDF	378	NA	0.495	ng/Sm^{3*}
— PCB	6	NA	14	ng/Sm^{3*}
— CB	4,848	NA	113	ng/Sm^{3*}
— CP	11,329	NA	391	ng/Sm^{3*}
— PAH	32,421	NA	2,438	ng/Sm^{3*}
PARTICULATE	3,893.7	NA	5.79	mg/Sm^{3*}
TRACE METALS				
— Sb	159	NA	ND	$\mu g/Sm^{3*}$
— As	196	NA	ND	$\mu g/Sm^{3*}$
— Cd	868	NA	ND	$\mu g/Sm^{3*}$
— Cr	1,491	NA	11.1	$\mu g/Sm^{3*}$
— Cu	3,219	NA	ND	$\mu g/Sm^{3*}$
— Pb	2,592	NA	39	$\mu g/Sm^{3*}$
— Hg	644	NA	14.1	$\mu g/Sm^{3*}$
— Ni	1,574	NA	5.2	μ $/Sm^{3*}$
— Zn	46,159	NA	ND	$\mu g/Sm^3$

* Corrected to 12% CO_2.



ASH	FABRIC FILTER ASH	
ASH RATE (dry)	1,317	Kg/h
TRACE ORGANICS		
— PCDD	112	ng/g
— PCDF	222	ng/g
— PCB	ND	ng/g
— CB	1,266	ng/g
— CP	4,336	ng/g
— PAH	4,780	ng/g
TRACE METALS		
— Sb	13	µg/g
— As	21	µg/g
— Cd	119	µg/g
— Cr	287	µg/g
— Cu	632	µg/g
— Pb	4,545	µg/g
— Hg	37	µg/g
— Ni	415	µg/g
— Zn	8,497	µg/g

APPENDIX C

SYMBOLS AND ABBREVIATIONS

APPENDIX C
SYMBOLS AND ABBREVIATIONS

SI Prefixes

Prefix	Symbol	Multiplication Factor	Exponent
mega	M	1 000 000	$= 10^6$
kilo	k	1 000	$= 10^3$
hecto	h	100	$= 10^2$
deca	da	10	$= 10^1$
unit	-	1	$= 10^0$
deci	d	0.1	$= 10^{-1}$
centi	c	0.01	$= 10^{-2}$
milli	m	0.001	$= 10^{-3}$
micro	μ	0.000 001	$= 10^{-6}$
nano	n	0.000 000 001	$= 10^{-9}$
pico	p	0.000 000 000 001	$= 10^{-12}$

Units

Symbol	Unit	Comments
Mass/Weight		
g	gram	-
tonne	metric tonne	1 tonne = 1 Mg
lb	pound	1 pound = 453.592g
Length		
m	metre	-
ft	foot	1 ft = 0.3048 m
Volume		
L	litre	-
m^3	cubic metre	1 m^3 = 1000 L
Nm^3	normal cubic metre	at standard conditions 25°C and 101.325 kPa
cm^3	cubic centimetre	
ft^3 or cf	cubic foot	1 ft^3 = 0.02832 m^3
Time		
s	second	-
m (min)	minute	1 min = 60 s
h (h)	hour	1 h = 3600 s
Temperature		
°C	degree Celsius	-
°F	degree Farenheit	-
Pressure		
bar	bar	-
Pa	Pascal	1 Pa = 10^{-5} bar

APPENDIX C
SYMBOLS AND ABBREVIATIONS
(Continued)

Acronyms	
ASTM	American Society for Testing and Materials
NITEP	National Incinerator Testing and Evaluation Program
EPA	Environmental Protection Agency - United States of America
ASME	American Society of Mechanical Engineers
Sampling and Analytical Terminology	
XAD-2	Amberlite Resin used to absorb organics
GC	Gas Chromatography
MS	Mass Spectrometry
ECD	Electron Capture Detector
MID	Multiple Ion Detection
MM5	Modified Method 5
CT	Characterization Test
PT	Performance Test
QA/QC	Quality Assurance/Quality Control
Compounds	
PCDD	Polychlorinated dibenzo-para-dioxins
PCDF	Polychlorinated dibenzo furans
PCB	Polychlorinated Biphenyls
PAH	Polycyclic Aromatic Hydrocarbons
THC	Total Hydrocarbons
TOX	Total Organic Halides
CP	Chlorophenols
CB	Chlorobenzenes
CO	Carbon Monoxide
CO_2	Carbon Dioxide
O_2	Oxygen
SO_2	Sulphur Dioxide
HCl	Hydrogen Chloride
TSP	Total Suspended Particulate or Particulate Matter
NaOH	Sodium Hydroxide
$KMnO_4$	Potassium Permanganate
H_2O	Water
H_2SO_4	Sulphuric Acid
HNO_3	Nitric Acid
Na_2SO_4	Sodium Sulphate
$HClO_4$	Perchloric Acid
$Ca(OH)_2$	Calcium Hydroxide

APPENDIX C
SYMBOLS AND ABBREVIATIONS
(Continued)

Metals	
Cd	Cadmium
Be	Beryllium
Mo	Molybdenum
Ca	Calcium
V	Vanadium
Al	Aluminum
Mg	Magnesium
Ba	Barium
K	Potassium
Na	Sodium
Zn	Zinc
Mn	Manganese
Co	Cobalt
Cu	Copper
Ag	Silver
Fe	Iron
Pb	Lead
Cr	Chromium
Ni	Nickel
Si	Silicon
Ti	Titanium
B	Boron
P	Phosphorus
Hg	Mercury
As	Arsenic
Sb	Antimony
Bi	Bismuth
Se	Selenium
Te	Tellerium
Sn	Tin
Miscellaneous	
ND	Not Detected
ppm	part per million
°	Degree (angle or temperature)
±	plus or minus
<	less than
>	greater than
ID	Induced Draft (fan)
d	dry
S	standardized gas conditions