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Retrofit of Waste-To-Energy Facilities Equipped with Electrostatic Precipitators

Volume I: Report

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RETROFIT OF WASTE-TO-ENERGY FACILITIES EQUIPPED WITH ELECTROSTATIC PRECIPITATORS

April, 1996

VOLUME I

REPORT

Prepared by
H. Gregor Rigo, Rigo & Rigo Associates, Inc.
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Under the direction of
ASME Research Committee on Industrial and Municipal Waste
Electrostatic Precipitator Retrofit Subcommittee
Department of Energy's National Renewable Energy Laboratory

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ABSTRACT

Many existing municipal waste combustion [MWC] facilities are equipped with electrostatic precipitators [ESPs]; few have acid gas control systems. Retrofitting these facilities with spray dryers and fabric filters to meet the emissions guidelines for existing facilities promulgated by the U.S. Environmental Protection Agency [EPA] on December 19, 1995 will be costly. To help lower the cost of compliance, a retrofit technology using water spray temperature reduction combined with dry acid gas control reagent and powdered activated carbon [PAC] injection was tested in November, 1995 as part of an American Society of Mechanical Engineers' [ASME] Center for Research and Technology Development [CRTD] effort supported in part by the Department of Energy's National Renewable Energy Laboratory [NREL] and directed by the ASME Research Committee on Industrial and Municipal Waste.

2,000 mg/dsm^3 @ 7% O_2 (150 lb/hr) of trona (a natural sodium sesquicarbonate ore) injected through a rapid dispersion lance successfully controlled more than 50 percent of the acid gases. This should let facilities under 250 TPD meet the small plant guidelines for acid gas control. Various levels of PAC were injected along with the trona. 300 mg/dsm^3 @ 7% O_2 of PAC provides a comfortable margin between the emissions limitations achieved and both large and small plant regulatory guidelines for tetra- through octa-chlorinated dibenzo-p-dioxins and dibenzofurans [PCDD/F] and mercury when the ESP is operated below 350°F. Bi-fluid nozzles were used to spray finely atomized water between the economizer outlet and ESP inlet to maintain temperatures in the desired 300-350°F range. Particulate and metals emissions limitations were met by this 400 ft^2/1,000 acft^2 specific collector area [SCA], 3-field ESP. Both the water sprays and PAC improved ESP performance.

The proof-of-concept demonstration was successful. With dry PAC, acid gas reagent injection, and temperature reduction, MWC emissions guidelines for facilities smaller than 250 TPD can be reliably met. Everything except the large facilities SO_2 and HCl guideline emissions limitations was achieved. Better acid gas control should be achievable with more reagent addition if the ESP is efficient enough to avoid violating particulate limits. Combustion related pollutants, CO and NO_x, require other control techniques whose demonstration was outside the scope of this effort.

PREFACE

This proof-of-concept demonstration test by the American Society of Mechanical Engineers' Center for Research and Technology Development was administered by Greg Barthold. Direction was provided by the Research Committee on Industrial and Municipal Waste—Electrostatic Precipitator Retrofit Subcommittee co-chaired by Dave Hoecke and Bob Sommerlad. Test oversight for the Research Committee was provided by Floyd Hasselriis.

The effort was sponsored by the Department of Energy's National Renewable Energy Laboratory [NREL], Golden, Colorado; facility owners and operators in Sumner County, Tennessee; Nashville, Tennessee; Grosse Point-Clinton, Michigan; Barron County, Wisconsin; Hampton, Virginia; and Ogden Corporation. The sponsor representatives: Phil Shepherd [NREL]; Jerry Corrick [Barron Co.]; Doug Taylor [Grosse Points-Clinton]; James Powers [Resource Authority of Tennessee, Sumner Co.]; Roger Beckham [Nashville]; John Austin [Hampton]; and Dave Sussman [Ogden], provided valuable input and oversight. The Vinyl Institute provided additional funding for this effort and Norit Americas Inc. supplied activated carbon and part of the feed system.

Special thanks go to the host, the Davis County Energy Recovery Facility. The efforts of LeGrand Bitter (District Manager), Jack Schmidt (Plant Manager), John Watson (Chief Operator), Bart Baker (Instrumentation), Don Leach (Residue Sampling) and the rest of the staff involved in making the modifications for this test, operating the facility to meet test requirements, obtaining samples and gathering performance data are gratefully acknowledged.

The Principal Investigator was H. Gregor Rigo (Rigo & Rigo Associates, Inc., Berea, Ohio) in association with A. John Chandler (A. J. Chandler & Associates Ltd., Toronto, Ontario). The stack gas emissions testing contractor was Bovar-Concord Environmental (Toronto, Ontario). The analytic laboratory was Zenon Environmental Laboratories (Burlington, Ontario) and the TCLP laboratory was NUS Laboratories (Pittsburgh, Pennsylvania). The extraordinary efforts of Bovar's Donna L. M. Dougherty and Zenon's Ron McCleod and everyone else associated with the successful completion of this effort are sincerely appreciated.

Trade names are used to identify specific equipment and supplies used in this demonstration test. Mention of specific trade names does not imply endorsement for specific use nor does it imply that alternative sources of supply are inferior.

Conventional units used in the trade are employed in this report to facilitate understanding. Metric equivalents are provided to facilitate engineering transfer.

EXECUTIVE SUMMARY

INTRODUCTION

On December 19, 1995, the USEPA promulgated New Source Performance Standards [NSPS] and Emissions Guidelines for municipal waste combustors [MWCs]. These guidelines restrict the emitted concentration of both criteria and hazardous air pollutants listed in Section 129 of the Clean Air Act. There are 135 electrostatic precipitator [ESP] equipped units in 54 facilities, representing more than 43,000 tons per day [TPD] (39,000 Mg/d) of municipal solid waste [MSW] disposal capacity; 5,200,000 lb/hr of cogenerated and direct steam sales; and 640 MW of electrical generating capacity that are significantly affected by these guidelines. Particularly affected are ESP-equipped MWCs smaller than 250 TPD. This category contains at least 54 units in 25 facilities. These small MWCs provide more than 5,300 TPD of MSW disposal capacity; 70 MW of electrical generating capacity; 860,000 lb/hr of steam sales; and more than 700 jobs. Many of these affected installations were built before dry scrubbers and ultra-high efficiency ESPs or fabric filters became the *de facto* standard in the mid-1980s. These older ESP-equipped facilities still provide useful services to the communities that invested in them. But, an economical way must be found to meet the guideline emissions limitations, otherwise, the residual economic value in these ESPs or, in extreme cases, the entire facility will be lost.

The Department of Energy's [DOE] National Renewable Energy Laboratory [NREL] supported an American Society of Mechanical Engineers' [ASME] Center for Research and Technology Development [CRTD] project directed by the electrostatic precipitator retrofit subcommittee of the ASME Research Committee on Industrial and Municipal Waste [RCIMW]. This work was instigated to assist communities operating ESP-equipped MWCs. A proof-of-concept demonstration test of an emissions control technique for these facilities was conducted to help keep these valuable investments operating and contributing to our nation's energy future. This program demonstrated the ability of an existing ESP-equipped MWC using flue gas temperature control, dry acid gas reagent injection and activated carbon addition to meet the emissions guidelines for small (<250 TPD) MWCs.

OBJECTIVES

The overall program objectives were:

- to determine the controlled emissions after applying a combination of reduced ESP operating temperature, acid gas reagent injection, and activated carbon addition; and,

- to demonstrate that ESP temperature reduction can be reliably accomplished.

The purpose of this test was to demonstrate achievement of the final 40 CFR 60 Subpart Cb emission guidelines, summarized in Table ES-1 for PCDD/F, mercury, HCl and SO_2. The proposed emissions guidelines (September 20, 1994) for small facilities shown in Table ES-1 served as a design basis for this effort.

Table ES-1 Emissions guidelines for existing facilities.

	September 20, 1994 Proposed		December 19, 1995 Guidelines	
	Large Plants	Small Plants	Large Plants	Small Plants
PCDD/F (ng/dsm^3)	30	60	30 60 w/ESP	125
Particulates (mg/dsm^3)	27	69	27	70
Cadmium (μg/dsm^3)	40	100	40	100
Lead (μg/dsm^3)	50	1,600	49	1,600
Mercury (μg/dsm^3)	80	80	80	80
Sulfur Dioxide				
Efficiency	75%	50%	75%	50%
Concentration (ppmdv)	35	80	31	80
Hydrogen Chloride				
Efficiency	95%	50%	95%	50%
Concentration (ppmdv)	35	250	31	250

Note: All concentrations at regulatory standard conditions (20°C & 760 mm_{Hg}) and 7% O_2.

APPROACH

It was imperative that the project be completed as soon as possible after contracts were signed on August 24, 1995 so facilities could include the results in their assessment of how to best meet the then pending emissions guidelines. To meet the expedited project schedule equipped host facilities had to have suitable operating permits or variances to conduct the testing and a dry sorbent injection system operational by the end of September 1995. Technology transfer issues required close coupling between the incinerator outlet and ESP inlet. An existing distributive control system, data logger and plant continuous emissions monitoring system [CEMS] for criteria pollutants (CO, NO_x and SO_x), and a continuous opacity monitoring system [COMS] were beneficial enhancements for the test. Selection of the Davis County Energy Recovery Facility [DCERF], Layton, Utah was approved by the Subcommittee, Advisory Committee and sponsors on August 30, 1995. As part of that approval, one advisor recommended, and all concurred, that a sodium-based reagent should be used to maximize the chance of meeting the then proposed acid gas emissions limitations. The final test protocol was approved on September 23, 1995.

The Facility

The demonstration test was conducted between November 17 and 28, 1995. The DCERF is a nominal 420 TPD (2 by 210 TPD) MWC. A back pressure turbine is used to generate electricity before the steam raised from burning waste is sent to the neighboring Hill Air Force Base district heating system. The facility has refractory

wall Seghers (combination rocking and sliding grate) furnaces and Zurn waterwall waste heat recovery steam generators which produce 51,344 lb/hr of 500°F, 500 psig steam when operating at maximum continuous rating [MCR].

The DCERF was built with a powdered limestone furnace injection system. After much experimenting with injection location and reagent, trona (a natural ore--sodium sesquicarbonate--used for acid gas control and as a cattle feed supplement) has been injected between the boiler outlet and economizer inlet since July 1993. Particulate emissions are controlled by a three-field Environmental Elements ESP with a specific collector area [SCA] of about 400 ft^2/1000 acfm.

Temperature Control

There is considerable experimental evidence that, once good combustion has been achieved, the predominant source of PCDD/Fs in MWCs is formation downstream of the active combustion zone (Kilgroe & Licata, 1996). Formation may take place in the gas phase, on particulate surfaces, or inside the particulate matter itself (Wilson, et al., 1995). Regardless of the actual mechanism, laboratory data indicate that temperature plays a significant role in the reaction. Figure ES-1 brings together much of the available PCDD/F and air pollution control system [APCS] temperature data. While the data are variable and system design and operating characteristics clearly affect PCDD/F stack concentrations, the effect of temperature is evident. Lower gas temperatures in the APCS are associated with lower PCDD/F concentrations in the stack gas. Furthermore, available data indicates that acid gas removal is enhanced at lower temperatures. For comparison, typical spray dryer absorbers have a practical lower temperature limit of 350°F.

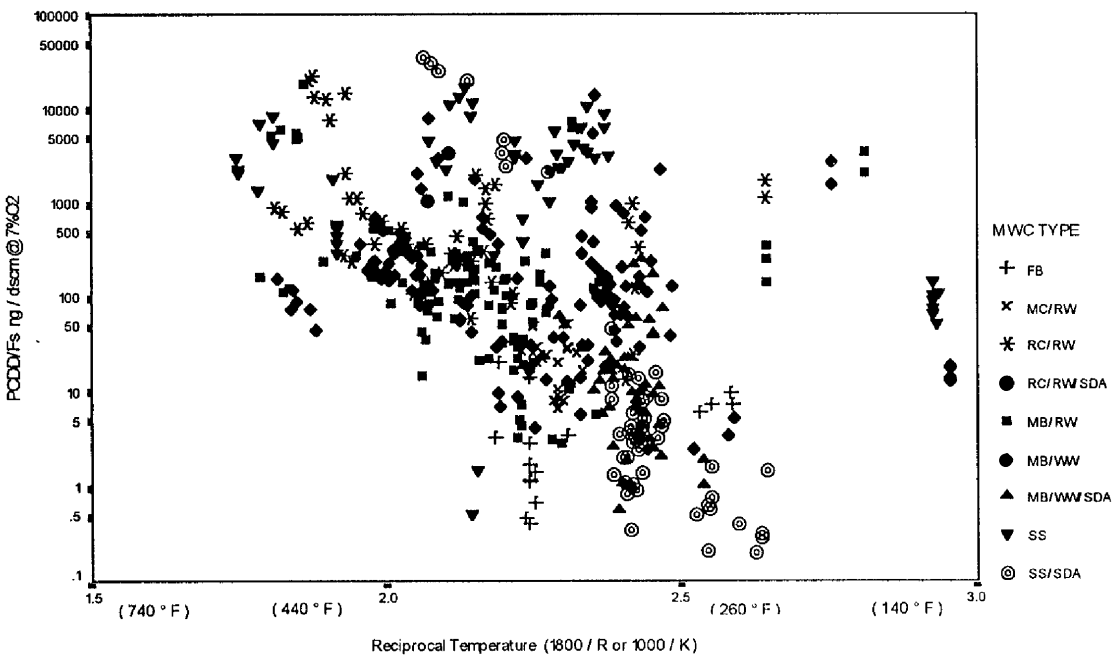

Figure ES-1 Relationship between stack concentrations of PCDD/Fs and reciprocal APCS inlet temperature.

Thermodynamic calculations indicate that each of the 210 TPD DCERF MWCs require about 9 gpm of water to reduce the temperature of their nominal 35,000 $dsft^3/hr$ stack flow from the normal economizer outlet temperature of 420°F to 300°F. These calculations were corroborated by field data during the test period, when the 300°F temperature target required the addition of 8.5 to 9.5 gpm of water.

A temperature-reducing water spray atomization system that economically and reliably delivers a very fine water spray was required due to the short distance for evaporation between the economizer outlet and ESP inlet. The bi-fluid atomizer based spray system was designed to produce 25 micron Sauter mean diameter water droplets. Such fine droplets theoretically evaporate within 0.4 seconds. This should minimize wall impingement. The DCERF demonstration test employed air atomization to meet installation time requirements and to minimize the cost. Steam driven bi-fluid atomizers are an alternative. To help achieve fine atomization, the water was preheated to about 170°F via an integral water heating loop designed into the lance. Preheating reduces the water's viscosity and produces a finer droplet for the same atomizing conditions.

The lance itself was fabricated from carbon steel pipe and three bi-fluid nozzles were employed. A 90° spray angle nozzle was placed in the middle and 60° spray angle nozzles were located on the quarter points. The nozzles were oriented to spray 10° above the duct centerline so that gravity would not cause wall impingement prior to droplet evaporation.

Sorbent Addition

Both trona and powdered hydrated lime were injected before and after the economizer during extensive tests at the facility between 1988 and 1993. Trona proved to be more effective on HCl than hydrated lime. Trona, ground to pass a 325 mesh sieve (<44 μm), is a locally available natural ore and its pricing is much more favorable than either lime or sodium bicarbonate at DCERF. Previous testing (Solvay, 1993) indicates that between 75 and 100 percent of stoichiometric [1] addition rates produce 50 percent acid gas reductions. If particulate emissions limitations are to be simultaneously met, reagent addition rate is limited by the particulate removal capability of the ESP. DCERF typically operates at a nominal stoichiometric ratio of 0.8:1. The baseline runs indicate that the actual stoichiometric ratio achieved during testing was between 66 and 97 percent.

Several reports suggest that powdered activated carbon [PAC] injection reduces PCDD/F emissions (Heath, 1995; Licata, et al., 1994; and Sierhuis, et al. 1994). While sulfur or iodine impregnated PAC have been suggested to perform better than ordinary PAC in some applications. Richman (1993) reported a lack of significant performance differences for a MWC using ordinary and sulfur augmented PAC. Based on this finding, ordinary PAC was chosen.

PAC can be obtained either pre-mixed with acid gas sorbent or packaged separately. If the correct mixture is known, the selection of pre-mixed versus separate feed systems is a facility-specific decision. For test purposes, however, the ability to independently control the reagent and PAC feed rates to alter experimental conditions required that separate systems be used. Analyses of the available data suggested that a 15 lb/hr PAC addition rate (200 mg/dsm^3 @ 7% O_2) should provide the necessary PCDD/F removal. The limited data suggested that less would be needed to meet mercury removal requirements. Since a purpose of this test was to demonstrate that an existing ESP-equipped MWC can be relatively inexpensively modified to meet the proposed PCDD/F and

[1]The stoichiometric trona addition rate—the amount needed to just neutralize all the HCl and SO_2—is 150 lb/hr/unit based upon median historic uncontrolled HCl (560 ppm_{dv} @ 7% O_2) and SO_2 (110 ppm_{dv} @ 7% O_2) concentrations at DCERF. For comparison, the stoichiometric sodium bicarbonate rate is 110 lb/hr/unit and the stoichiometric hydrated lime rate is 96 lb/hr/unit.

mercury Emissions Guidelines for Small Plants (<250 TPD), a second addition rate of 30 lb/hr (400 mg/dsm^3 @ 7% O_2) was selected to provide a safe fall-back position.

The PAC was Norit DARCO FGD made from lignite coal and pulverized so that 95 percent passed a 325 mesh screen (<44 μm). This is the same type of PAC used in USEPA testing at Stanislaus County, CA (1993) and Camden, NJ (1993) thereby eliminating a potential difference (confounding factor) between the test programs. It must be recognized, however, that both Stanislaus and Camden are equipped with spray dry absorbers and Stanislaus has a fabric filter rather than an ESP. As a result, the data sets cannot necessarily be directly merged and analyzed as a single experiment. Testing at DCERF, however, was conducted at an ESP inlet temperature about 100°F (55°C) higher than previous tests. Thus, this work extends the range of published information.

The trona and the PAC were combined in the feed chute to the plant's 10 psig trona injection system eductor and injected below the economizer through a specially designed rapid dispersion dry sorbent injection lance that visually achieves full duct coverage within 3 to 5 feet. The lance is the bottom 2/3 of a piece of 2-inch diameter Schedule 40 pipe with progressively deeper 45° baffles inserted every 18 inches to disperse the reagent.

FINDINGS AND CONCLUSIONS

Emissions Control Performance

Performance models for PCDD/F, Hg, HCl and SO_2 removal (PAC and trona effects), developed using Langmuir isotherms as a theoretical construct, were used to calculate routinely achievable emissions limitations (95 percent statistical confidence level upper prediction limits designed to contain the next five 3-run average test results) from the data. Overall, the results indicate that the DCERF and other facilities using dry sorbent injection, PAC addition and APCS inlet temperature control can meet the small MWC category emissions limitations for all pollutants and would likely meet the large facility guidelines for all regulated pollutants except for the acid gases. NO_x control is required at large, non-refractory wall MWC facilities, but demonstrating such a retrofit was outside the scope of this effort.

The PAC performance results indicated that 11.25 lb/hr (300 mg/dsm^3 @ 7% O_2) should be able to meet the large plant emissions limitations for PCDD/F and mercury from ESP-equipped MWCs. To provide a safety margin, some temperature control is indicated, but there is little apparent value in dropping the APCS inlet temperature below 350°F for PCDD/F and mercury control.

Injecting reagents increased particulate emissions slightly compared to zero reagent injection rate measurements at normal ESP operating temperatures. When coupled with water spray temperature control, sorbent injection had no effect on particulate emissions. 3-run average cadmium and lead concentrations remained below small and large plant regulatory limits, but spikes (individual high runs) are evident.

The acid gas control results for trona injection only incorporate the feed rate variability induced by changes in stack gas flow and nominal trona feed fluctuations because the experiment did not call for adjusting this feed rate. The results indicate that feed rates above 1,700 mg/dsm^3 @ 7% O_2 (125 lb/hr) should keep the HCl and SO_2 removal efficiency safely above the mandated 50 percent removal level for small MWC facilities. It does not appear that dry acid gas sorbent injection/ESP systems can meet the 75 percent SO_2 and 95 percent HCl reductions required for large facilities without causing exceedances of the particulate emissions limitations; however, specific facilities with very efficient ESPs may be successful. Also, other sodium based reagents (nacolite and sodium bicarbonate, for example) and calcium based reagents (hydrated lime, for example), could provide technically equivalent, but economically superior performance depending on site-specific factors. This proof-of-concept demonstration test, however, shows which emissions limitations can be met by a DSI/ESP

retrofit and provides a basis for moving ahead. Economic optimization can follow at specific sites since the same equipment is involved regardless of the dry powdered reagent employed.

The effect of temperature reductions alone on PCDD/F and mercury removal was not very significant between the 420°F normal operating temperature and the 300°F lowest tested temperature. However, reducing temperature had a favorable effect when combined with the addition of PAC. HCl and SO_2 removal also benefited from reduced temperature operation.

Field Observations

Comparison of plant operating data before testing commenced, during each test series and during non-test times between runs and after testing, indicates that the plant was operating normally during the demonstration test.

The water spray lance performed as expected. Water flow rates and temperature drops corresponded to the values calculated using elementary thermodynamics. A 6-inch diameter washer was used to minimize fly ash build up around each nozzle head. Inspection after 3 days showed the heads to be free of ash, but the washers were caked with a soft covering. After a further 8 days of operation with the spray heads and washers reoriented from 10° above the duct centerline to 35° below the duct centerline, harder material was caked on and about the nozzle faces. This coating may have accounted for the inability to achieve the desired temperature reduction during the last two days of testing.

A plug valve was used to control the water flow from the 230 psig pumps to the nozzle. Flow commenced at 55 percent of the valve-wide-open position (3.5 gpm of flow) because there was too much valve resistance to overcome the atomizing air back pressure at lower flows. The valve-wide-open flow was 12 gpm. A different control valve type or variable air pressure operation will be needed at facilities requiring a greater operating range.

Lowering the gas temperature from 420°F to 300°F also reduced the gas velocity by about 10 percent. Lower velocities induce more particulate settling than the plant experiences at higher temperatures with their inherently higher gas velocities. Theoretical calculations and stack gas flow measurements indicate that the average gas velocity dropped to about 90 percent of design when the temperature was reduced from 420°F to 350°F using water sprays. The reduced velocity effect was probably exacerbated by particle agglomeration. As the fly ash, PAC and trona laden flue gases pass through the spray zone, the water can cause some of the particulates to combine into larger aggregates. Such agglomerates settle faster than the individual particles. The resulting sedimentation and build-up can lead to plugging of the economizer. Accumulated particulate can slough off the bottom of the 60° inclined breaching leaving the economizer and slide back on top of the economizer. To solve this problem, at least an intercepting hopper is required. Installation of a separate, custom designed contact chamber is a more robust solution that should be investigated and employed when room is available.

The high efficiency ESP performed well. To avoid confounding the experiment, the spark rate and secondary voltage controllers were not adjusted. Normally, the first two fields spark rate is around 230 sparks per minute and the fields operate with 23 kV potential differences; the third field ranges between 0 and 100 sparks per minute and a similar applied voltage. These characteristics did not change when either 15 or 30 lb/hr of PAC was introduced or when the trona addition was stopped. With the water sprays, however, the spark rate dropped dramatically in the first two fields to less than 10 and 50 sparks per minute respectively. The third field was rarely above the 10 sparks per minute range. The secondary voltage applied to all three fields also rose to between 30 to 32 kV and exhibited much less variability. These changes are all beneficial. The secondary voltage can be increased farther than the automatic adjustment took it. This would improve the particulate control system performance.

TEST PROGRAM

A fractional factorial[2] test plan—three operating temperatures, two trona feed rates and three PAC feed rates—with one designed replicated test condition was used. The order of testing was random. The replicate was assigned to the low temperature, low PAC feed, because the information available prior to the start of testing indicated that this was the one most likely to reliably and economically achieve the program objective.

The project plan had 10 days of scheduled testing, with two additional testing days allowed for field difficulties. Because the field work proceeded with few problems after the first day, an extra day of testing was available. The 30 lb/hr PAC, 150 lb/hr trona and 300°F ESP inlet temperature condition was replicated because contemporaneous field observations indicated that the PAC feed was not uniform. The target temperatures were not achieved on the last two days of testing due to economizer fouling that raised the flue gas temperature entering the water spray zone. The temperature on these days was in the range of 325°F, so an extra, unplanned temperature condition was achieved.

Plant operating conditions and reagent injection rates were established the evening before to help ensure that steady-state operating conditions were achieved before testing began. Sampling equipment setup commenced at dawn. Simultaneous metals Method 29 and PCDD/F Method 23 test runs were conducted on opposite traverses in the stack. Following completion of these tests, a non-traversing HCl (Method 26) test run was performed. At the completion of the HCl run, the testing sequence was repeated. Two complete sets of runs were finished about 6 p.m. each night.

Plant operating data were collected for the week prior to testing, throughout testing, and for the week following testing using the plant's process monitors. The data historian was used to continuously record plant operating conditions. Combined residue (bottom ash and APCS) was sampled following the plant's residue sampling protocol.

[2]A factorial plan tests all possible combinations and permutations of the factor levels in the design; a fractional factorial plan only tests a selected subset.

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UNITS OF MEASUREMENT, ABBREVIATIONS AND ACRONYMS

AA	Atomic Absorption
acfm	actual cubic feet per minute
ACS	American Chemical Society
ANOVA	Analysis of Variance
APCS	Air Pollution Control System
ASME	The American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BDL	Below Detection Limit
BQL	Below Quantitation Limits
Btu	British Thermal Units
CAA	Clean Air Act
Cb	Subpart Cb of 40 CFR 60, Emissions Guidelines for Existing Municipal Waste Combustors
Cd	Cadmium
CEMS	Continuous Emissions Monitoring System
CGA	Cylinder Gas Audit
Cl_2	Chlorine
COMS	Continuous Opacity Monitoring System
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRTD	Center for Research and Technology Development
CV	Coefficient of Variation
CVAA	Cold Vapor Atomic Absorption
DCERF	Davis County Energy Recovery Facility
DCS	Distributive Control System
DI	deionized
DL	Detection Limit
DOE	Department of Energy
$dsft^3$	dry standard cubic foot
DSI	Dry Sorbent Injection
dsm^3	dry standard cubic meter (20°C & 760 mm_{Hg})
EMC	Estimated Maximum Concentration
ESP	Electrostatic Precipitator
F	Fluorene
FB	Fluidized Bed
FSI	Furnace Sorbent Injection
g	gram
GC	Gas Chromatography
gpm	gallons per minute
$gr/dsft^3$	grains per dry standard cubic foot
HCl	Hydrogen Chloride
h	hour
H	Hydrogen
HF	Hydrogen Fluoride
Hg	Mercury
HNO_3	Nitric Acid
HpCDD	Heptachlorodibenzo-p-dioxins

UNITS OF MEASUREMENT, ABBREVIATIONS AND ACRONYMS

HpCDF	Heptachlorodibenzo-furans
HxCDD	Hexachlorodibenzo-p-dioxins
HxCDF	Hexachlorodibenzo-furans
HPLC	High Pressure Liquid Chromatography
IC	Ion Chromatography
ICAP	Inductively Coupled Argon Plasma
ln	natural logarithm
IQR	Interquartile Range
ITEQ	amount of 2,3,7,8 TCDD equal to the total PCDD/F calculated using ITEFs
ITEF	International Toxicity Equivalency Factor
K	Kelvin
kP	kilopascals
$KMnO_4$	Potassium Permanganate
kV	kilovolts
lb	pound
LOQ	Limit of Quantification
LQL	Laboratory Quantification Limit
m	minute
MAD	Median Absolute Difference
MB	Mass Burn combustor
MC	Modular Combustor
MCR	Maximum Continuous Rating
mg	milligrams
Mg/d	Megagram (1,000 kg) per day
MM5	Modified Method 5
MR	Mean Ratio
MS	Mass Spectrometry
MSW	Municipal Solid Waste
MW	megawatts
MW	Molecular Weight
MWC	Municipal Waste Combustor
N	Nitrogen
NaOH	Sodium Hydroxide
ng	nanogram
NIST	National Institute of Science and Technology
NO_x	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
NSPS	New Source Performance Standards
O_2	Oxygen
OCDD	Octachlorodibenzo-p-dioxin
OCDF	Octachlorodibenzo-furan
PAC	Powdered Activated Carbon
PAH	Polyaromatic Hydrocarbons
Pb	Lead
PCB	Polychlorinated Biphenyls
PCDD	Sum of tetra through octa polychlorinated dibenzo-p-dioxins homologues
PCDD/F	PCDD and PCDF, aka "dioxins"
PCDF	Sum of tetra through octa polychlorinated dibenzofurans homologues

UNITS OF MEASUREMENT, ABBREVIATIONS AND ACRONYMS

PD	Percent Difference
PeCDD	polychlorinated dibenzo-p-dioxins
PeCDF	polychlorinated dibenzofurans
PEMS	Process Emissions Monitoring System
pg	picograms
pH	ionization potential ($\log_{10}$ of hydrogen ion concentration)
ppmdv	parts per million dry volume
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gauge
QA	Quality Assurance
QC	Quality Control
r	correlation coefficient
R	Rankine
RC	Rotary Combustor
RCIMW	Research Committee on Industrial and Municipal Waste
RCRA	Resource Conservation and Recovery Act
RPD	Relevant Percent Difference
RSD	Relative Standard Deviation
RW	Refractory Wall
SCA	Specific Collector Area (ft^2/1000 $acft^3$/m)
SDA	Spray Dryer Absorber
scfm	standard cubic feet per minute
SE	Standard Error
SIM	Selected Ion Monitoring
SMMD	Studentized Maximum Modulus Distribute
SO_2	Sulfur Dioxide
SO_x	Oxides of Sulfur
SS	Spreader Stoker combustor
Standard (conditions)	20°C, 760 mm_{Hg} or 68°F, 14.7 psia
TCDD	Tetrachlorodibenzo-p-dioxin
TCDF	Tetrachlorodibenzo-furan
TCLP	Toxic Characteristics Leaching Procedure
T_{inv}	Inverse Absolute Temperature (1800/R or 1000/K)
TPD	Tons Per Day
THC	Total Hydrocarbons
TSP	Total Suspended Particulates
μg	microgram
UPL	Upper Prediction Limit
USEPA	United States Environmental Protection Agency
UTL	Upper Tolerance Limit
WW	Waterwall combustor

SECTION 1— INTRODUCTION

1.1 Background

The American Society of Mechanical Engineers' [ASME] Center for Research and Technology Development [CRTD] was awarded a subcontract by the Department of Energy's National Renewable Energy Laboratory [NREL] to demonstrate the technical performance and viability of flue gas temperature control in combination with dry acid gas reagent and activated carbon injection at an existing electrostatic precipitator [ESP] equipped municipal waste combustor [MWC].

The objective of this proof-of-concept demonstration test was to economically and reliably meet the then proposed 40 CFR 60 Subpart Cb Emissions Guidelines for MWCs at existing ESP equipped facilities with emphasis placed on small facilities that were not covered by the previously promulgated Guidelines.

Testing was conducted at the 2 by 210 TPD, ESP equipped MWC at the Davis County Energy Recovery Facility [DCERF] in Layton, Utah. The test plan called for duplicate metals (Cd, Pb and Hg), dioxin and HCl sampling runs at each test condition. Continuous emissions monitors were used to characterize SO_2, NO_x and CO. Prescribed test methods and laboratory procedures were followed throughout. These are documented in the September 22, 1995 Test Protocol (see Volume III of this report).

1.2 Site Selection Criteria

When the research contract was signed in late August 1995, mandatory retrofit requirements were imminent. Available data like that plotted in Figure ES-1 relating stack temperature and PCDD/F concentrations provided a strong indication that reducing the ESP inlet temperature could control dioxins. Equivalent displays relating mercury, acid gases, and PCDD/F to PAC and dry acid gas reagent injection rates showed the potential for achieving at least the proposed small plant standards and most, if not all, the large plant standards. Reducing the air pollution control system operating temperature and adding reasonable acid gas sorbent and activated carbon to incinerator flue gases should theoretically allow existing ESP equipped MWCs to economically meet proposed guidelines.

Field experience, however, has shown that it is difficult to reliably reduce ESP temperatures using evaporative (water spray) cooling techniques because of the typically short distance between MWC outlets and ESP inlets at existing installations. There is good reason to believe, however, that requisite temperatures can be successfully achieved using air or steam atomizers designed to produce a fine (25 micron Sauter mean diameter) cooling spray.

These considerations led to the following mandatory site selection requirements:

- Close coupled ESP—this maximizes the likelihood of successful technology transfer to other facilities;
- Single chamber mass burn type incinerator—since particulate carry-over may participate in PCDD/F formation;
- Dry injection in use by Sept. 15, 1995—to allow stable operation prior to the start of testing; and
- Existing permits (or a variance) that allowed for testing—the schedule dictated that protracted regulatory negotiations were not possible.

It was preferred that the plant have:

- a DCS with PC interface for routine plant data logging;
- CEMS for CO, O_2, NO_x, SO_x & COMS for Opacity; and
- both APCS and combined residue stream access for sampling.

The characteristics of U.S. ESP equipped MWC facilities were reviewed. A number of potential sites were identified and contacted to discern their interest in hosting this proof-of-concept demonstration test. The DCERF met both the mandatory and preferred site selection criteria. This facility agreed to be the host facility. The selection was presented to and confirmed by the project sponsors, advisors and the ASME Research Committee on Municipal and Industrial Waste [RCIMW] ESP Retrofit Subcommittee.

During the site confirmation meeting, one advisor recommended that a sodium based acid gas control reagent be used to maximize the likelihood of meeting the acid gas emissions limitations. The sponsors, advisors, RCIMW subcommittee and Principal Investigator agreed with the recommendation. It was further suggested that sodium bicarbonate be used instead of trona to facilitate technology transfer. Attempts were made to procure a supply, but the project budget would not support the sizable price difference between locally available trona* and imported sodium bicarbonate.

1.3 Overall Test Design

To accomplish the program objectives, the 4 x 3 fractional factorial test plan with one replicated test condition shown in Table 1-1 was developed. Nine distinct emissions control conditions (three ESP operating temperatures and three levels of activated carbon addition with the high temperature, low activated carbon addition run replaced by a no acid gas reagent at the medium temperature condition) were planned for testing while the balance of the plant operated normally. A designed replicate was included to provide a measure of reproducibility and experimental error. An extra temperature condition (325°F) was achieved when the designed experimental temperature could not be maintained during the last two days of testing.

Test condition order was developed by randomizing the 3 x 3 test matrix that contained the temperature and PAC levels. The high temperature, low PAC test condition was replaced by an intermediate temperature, no reagent or activated carbon test to provide baseline data. Since the purpose of this test was to demonstrate achievement of the small plant MWC emission guidelines, the replicate was assigned on engineering grounds to the operating configuration believed most likely to achieve the program objective: 30 lb/hr of PAC, 150 lb/hr trona, and 350°F APCS temperature.

1.4 Test Execution

Delays in getting the water spray system operational caused the sequence of testing to be altered to the final test pattern shown in Table 1-2. Essentially, all test conditions that did not require temperature reduction were executed first, then the balance of the test pattern was executed in the original order. During the scheduled low temperature, high PAC test, the PAC feeder seemed to be malfunctioning. Consequently, this condition was replicated at the end of the test. Also, the testing on the first day took longer than planned—only the first set of runs was accomplished by mid-afternoon. That condition was, therefore,

* The trona used at DCERF is a waste stream from grinding trona to make a cattle feed supplement. While very useful for this purpose, being 98% sodium sesquicarbonate, it is too fine to use in cattle feed. Hence the good local price.

continued the next day. Thus, there are a total of three metals and organics runs and four HCl runs for the day 1 test conditions.

Table 1-1 Original test plan matrix showing the day each condition was to be tested.

	ESP OPERATING TEMPERATURE		
	Normal Ops about 420° F	Intermediate 350° F	Minimum 300° F
No AG reagent or PAC	-	6	-
AG reagent only	2	9	5
AG reagent + low PAC	-	8	10
AG reagent + high PAC	7	1,3	4

Table 1-2 Executed test plan matrix showing the day each condition was tested.

	ESP OPERATING TEMPERATURE			
	Normal Ops about 420° F	Intermediate 350° F	325°F	Minimum 300° F
No AG reagent or PAC	3	-		-
AG reagent only	1	9		6
AG reagent + low PAC	-	8	10	-
AG reagent + high PAC	2	4,7	11	5

Plant operations, furnace conditions and CEMS data (CO, O_2 and opacity) were continuously recorded. 15-minute averages were obtained starting the week before testing and continuing one week after testing was completed. These data were recorded to establish normal incinerator operating characteristics and enable demonstration that the facility was operating normally during the proof-of-concept demonstration test.

The following MWC operating conditions were met to the greatest practical extent:

- operate at maximum continuous rating [MCR] steam flow
- hold the specified ESP temperature (nominally 420, 350 or 300 °F)
- inject targeted acid gas reagent (0 or 150 lb/hr of trona—0 or 2,000 mg/dsm^3 @ 7% O_2 which is a nominal stoichiometric ratio of 1:1) and

- maintain activated carbon injection rate at the specified test condition rate (0, 15 and 30 lb/hr—0, 200 and 400 mg/dsm^3 @ 7% O_2).

When operations were disrupted during the testing, the affected runs were suspended until the problem was corrected.

Each test condition was established at the end of testing the day before. Testing commenced at dawn the next day. The following emissions were measured at the stack:

- Method 29 front-half particulate matter, lead, cadmium and mercury,
- Method 26 HCl,
- Method 23 Dioxins and Furans—(2,3,7,8 substituted PCDD/F isomers and homologue totals)
- CEMS for CO, NO_x, and SO_2
- Continuous Opacity Monitoring System [COMS] for opacity.

Method 23 and 29 sampling systems (trains) were operated simultaneously, but on opposing traverses; one traversing West to East, the other North to South, to obtain nominal 2-hour samples. Then, a 1-hour Method 26 sample was extracted. Finally, the pattern was repeated so that two complete sets of runs were obtained each day.

Grab samples of ESP residues were taken near the end of each day's testing. Combined ash samples were collected and handled by plant personnel throughout the proof-of-concept demonstration test whenever residues were removed from the site.

Plant operations and testing procedures were observed by the Principal Investigator. An ASME RCIMW Committee representative was on-site to provide independent observation and oversight. Project sponsors visited the facility during testing.

The Project Plan and implemented demonstration test program met EPA Level IV Quality Assurance requirements. Testing substantially conformed to the approved test protocol (Volume III), including the laboratory methods and field procedures.

SECTION 2—DESCRIPTION OF TEST BED

2.1 Host Facility Characteristics

The Davis County Energy Recovery Facility is a nominal 420 TPD (200 Mg/d) MWC that uses a back pressure turbine to generate electricity and export steam to neighboring Hill Air Force Base. The facility has two 210 TPD refractory wall Seghers (combination rocking and sliding grate) furnaces and Zurn Industries waterwall waste heat recovery steam generators with a MCR of 51,344 lb/hr of 500°F, 500 psig steam. Figure 2-1 is a photograph of the facility. The scale house and tipping hall are to the right. The high rise portion in the middle is the top of the pit. The turbine hall and air cooled condenser are visible to the left. The stack is to the far left. Figure 2-2 shows the stack and testing platform. The unit tested was the "B" unit shown on the left-hand side of the picture.

The facility was built with a powdered limestone furnace sorbent injection [FSI] system that is now being used to inject trona (a natural sodium sesquicarbonate reagent used for acid gas control) between the boiler outlet and economizer at the location shown on Figure 2-3 and pictured in Figure 2-4.

Particulate emissions are controlled by a three-field Environmental Elements ESP with a SCA of about 400 ft^2/1000 acfm. The two incinerator units discharge through a bi-flue stack. The facility has a Foxboro distributive control system [DCS] with DEC MicroVAX data historian. Compliance monitors include an O_2 diluent corrected CO CEMS and COMS. The facility also has a process emissions monitoring system that analyzes NO_x and SO_x from one unit at a time.

Table 2-1 is a heat balance for the facility. The balance assumes 4,500 Btu/lb of MSW is being burned to raise 51,344 lb/hr of steam. These are the plant's MCR operating conditions.

Figure 2-5 is a block diagram showing overall facility operations. MSW is delivered in trucks, weighed and then discharged either directly into the enclosed storage pit or the adjacent, enclosed tipping hall when the MSW at the edge of the pit is too high. As MSW is loaded into the pit from the tipping hall floor by a front-end loader, readily identifiable oversized and bulky waste that will jam the MWCs and large quantities of undesirable materials, such as sheet rock, are separated for alternate management.

An orange-peel type grapple is used to mix and manage the waste in the enclosed pit. The grapple is also used to transfer MSW from the pit to the MWC feed hoppers. Once in the feed hoppers, the MSW is metered onto the 5-section Seghers grate (see Figure 2-6).

Combustion air is taken from the pit area to minimize the potential of fugitive emissions, and from near the building roof when preheated combustion air is needed. Combustion air is introduced both under (under-fire air) and over (over-fire air) the grate to sustain controlled combustion. The excess oxygen level in this refractory wall unit is maintained around 10 percent. The secondary air is introduced through the furnace side walls, over the fuel bed along the length of the grate. This is done to keep furnace temperatures within acceptable operating limits and minimize sidewall slagging. Sidewall slagging is an ongoing problem. When slag accumulates, it can snag unburned material in the fuel bed and disrupt the smooth flow of waste. When this happens, grate sections are uncovered, air distribution becomes unbalanced and carbon monoxide emissions increase. An industrial, 12 gauge shotgun is routinely used to remove sidewall slag accumulations while the unit is on-line.

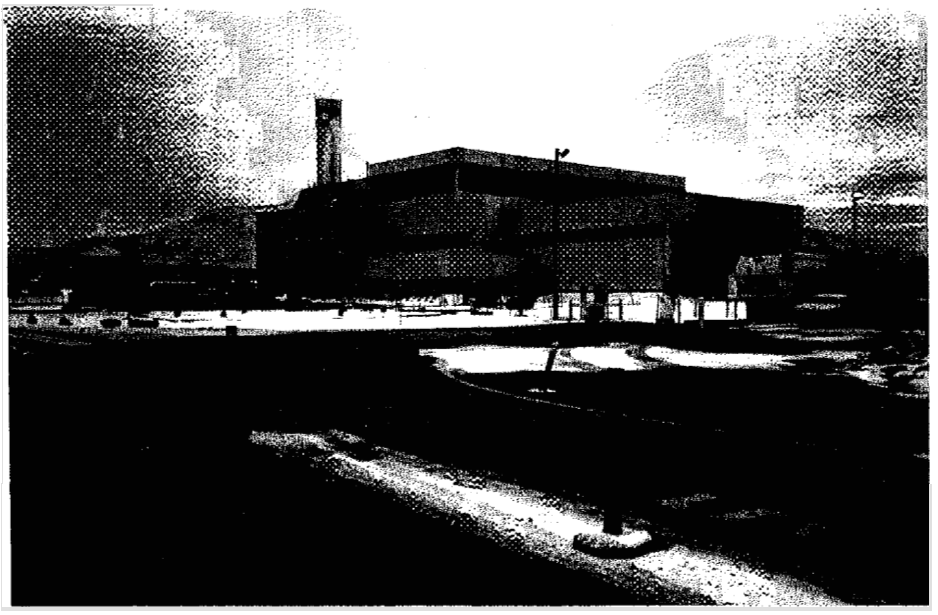

Figure 2-1 Davis County Energy Recovery Facility.

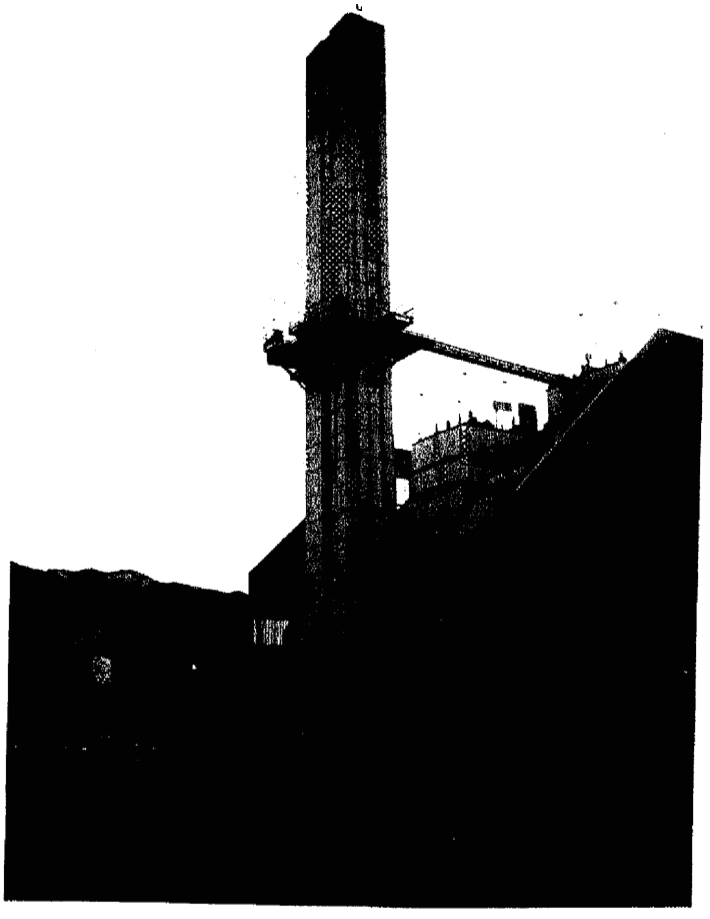

Figure 2-2 DCERF stack and ESPs.

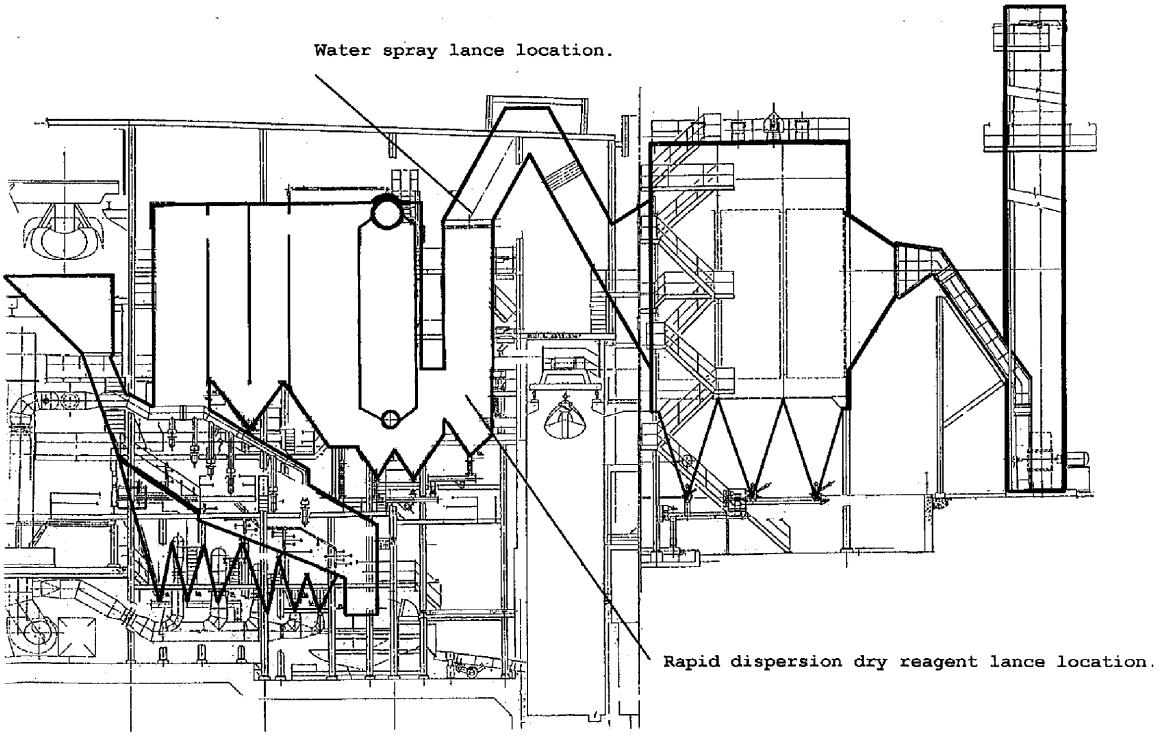

Figure 2-3 Boiler cross section drawing.

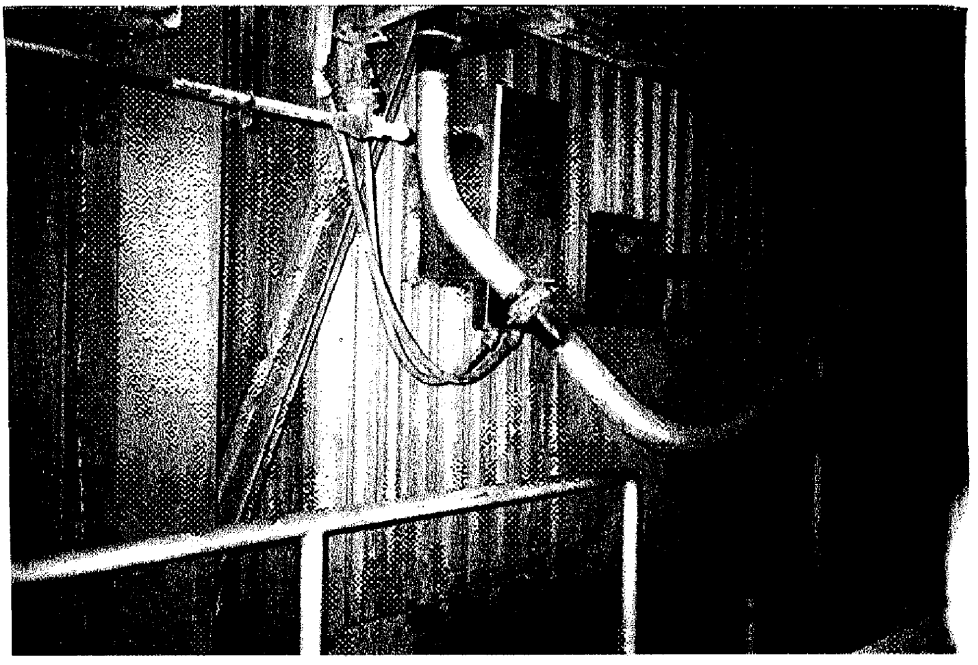

Figure 2-4 Dry sorbent injection location at the bottom of the economizer.

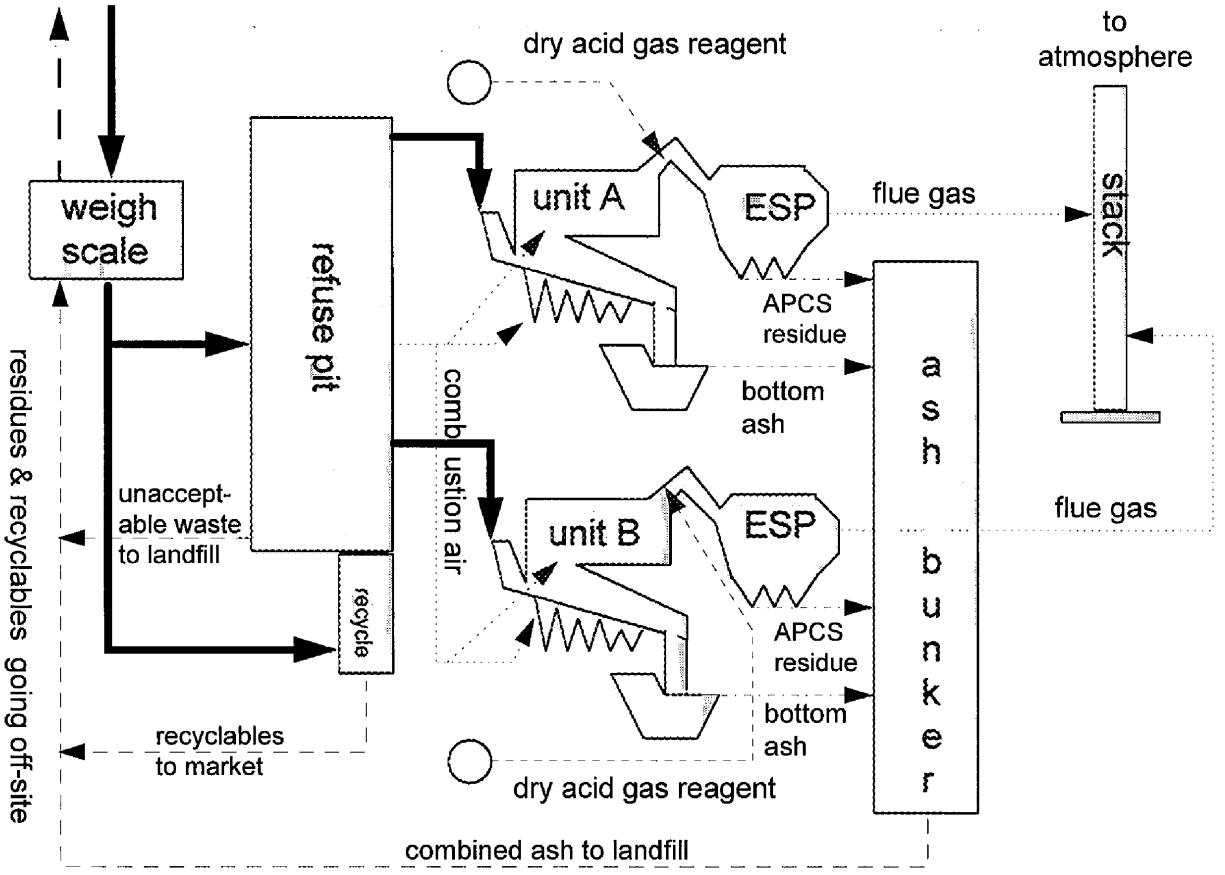

Figure 2-5 Schematic flow diagram of the DCERF.

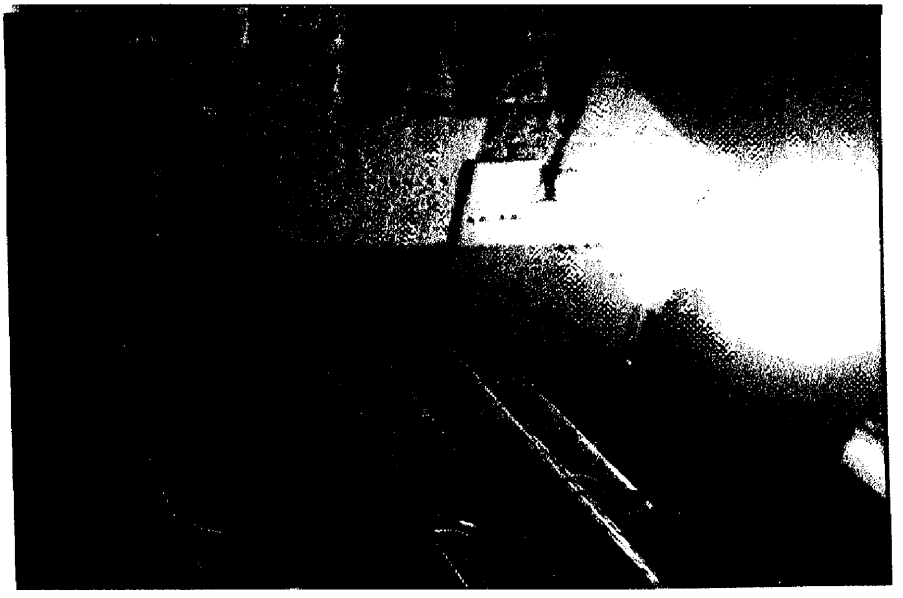

Figure 2-6 Inside the refractory wall furnace at DCERF.

Table 2-1 Combustion and heat balance for a DCERF unit burning 4,500 Btu/lb MSW

MODIFIED June 1, 1992
DAVIS COUNTY CONDITIONS
Run Date: 27-Mar-96 07:35 AM

FUEL CHARACTERISTICS	
C, % by weight	24.89
H2, % by weight	3.22
N2, % by weight	0.34
S, % by weight	0.13
O2, % by weight	19.38
Cl2, % by weight	0.24
H2O, % by weight	31.80
ASH, % by weight	20.00
HHV, Btu/lb	4,500
Fd, DSCF/MBtu	9,113
Fc, DSCF of CO2/MBtu	1,775
Fo, F ratio	1.08

SYSTEM CHARACTERISTICS	
Main Steam Flow, lb/hr	56,000
S.H. outlet press.. psig	500
S.H. outlet temp.. deg F	500
S.H.outlet enthalpy, Btu/lb	1,229.1
Feedwater press.. psig	600
Feedwater temp.. deg F	300
F.W.inlet enthalpy, Btu/lb	269.6
Drum press.. psig	571
Drum temp.(sat.) deg F	483
Drum sat vapor enth.,Btu/lb	1,203.4
Drum sat liq. enth., Btu/lb	468.0
Blow Down	1.0%
Misc. Steam Leaks & Losses	1.5%
Fraction of Ash to Boiler	10%
Grate ash discharge temp, F	250
UBC in Fly ash	8%
UBC in Bottom Ash	5%
Residue, lb-residue/lb-fuel	21.1%
Avg temperature of residue, F	268
Unburned Comb. loss, %	2.4
UBC in residue , %	5.3
Gas temp lvg econimizer, F	425
Gas temp lvg air heater, F	425
U.F.A. Steam Heater Rise, F	0
Radiation loss, %	3.0
Sensible heat in residue, %	0.2
Unaccounted for loss, %	1.0
Reference Temperature, F	60
Ambient Air Temperture, F	60
Total Excess Air	115%
Fraction air under grate	70%
Excess Air Supplied by Fans, %	103.7
weight flue gas recirculation	0%
General Air leakage-% of Theo.	11.3%
deNOx Carrier air--% of Theo.	0.0%

MOLES/100 lbs FUEL actually burned adjustment for UBC as proportion of heat lost to unburned combustibles	
C =	2.023
H2 =	1.559
S =	0.004
O2 =	0.591
N2 =	0.012
H2O =	1.765
Cl =	0.007

THERO. O2 REQ'D, MOL/100 LBS FUEL	
For: C + O2 = CO2	2.023
For: 2H2 + O2= H2O	0.780
For: S + O2 = SO2	0.004
For: available O2 & Cl	-0.598
Theo. mols O2 to be supplied	2.209
Wet Theo. Air, lb air/lb fuel	3.076
Mols dry air./ mols O2	4.764
Moles Dry air /lb fuel	0.226
Lb. dry air req'd/lb fuel	6.528
Lb. H2O in air/lb fuel	0.085
Lb. Std. Air req'd/lb fuel	6.613

FLUE GAS ANALYSIS	
Moles HCl/ lb fuel	0.00007
Moles CO2/ lb fuel	0.02023
Moles H2O/ lb fuel	0.03789
Moles SO2/ lb fuel	0.00004
Moles N2 / lb fuel	0.17889
Moles O2 / lb fuel	0.02540
Tot. Mols Flue gas/lb fuel	0.26252

FLUE GAS CHARACTERISTICS		
Partial Pressures		
	P(CO2)	1.133
	P(H2O)	2.122
	P(SO2)	0.002
Percent by Volume (Orsat)		
	% CO2	9.0
	% O2	11.3
	PPM SO2	176
	PPM HCl	294
Gas weights, lb gas/lb fuel		
Lb. HCl/lb fuel		0.002
Lb. CO2/lb fuel		0.890
Lb. H2O/lb fuel		0.683
Lb. SO2/lb fuel		0.003
Lb. N2/lb fuel		5.011
Lb. O2/lb fueL		0.813
Lb. Dry flu gas/lb fuel burnd		8.719
Lb. Wet flu gas/lb fuel burnd		7.402
Flue gas molecular weight		28.196
H2O in gas, % by weight		9.222

MOLECULAR WEIGHTS	
Hydrochloric Acid (HCl)	36.46
Carbon (C)	12.01
Hydrogen (H2)	2.02
Sulfur (S)	32.06
Oxygen (O2)	32.00
Nitrogen (N2)	28.01
Water (H2O)	18.02
Chlorine (CL2)	70.91
Carbon Dioxide (CO2)	44.01
Sulfur Dioxide (SO2)	64.06
Carbon Monoxide (CO)	28.01

STANDARD AIR COMPOSITION	
O2, % by volume	20.99
N2, % by volume	79.01
H2O, % by weight	1.30
Molecular weight dry air	28.85

ADJUSTMENTS TO HHV FOR DIFFERING CONDITIONS		
Sensible Heat in Fuel	Btu/lb	0.0
Sensible Heat in Air	Btu/lb	0.0
Compression Heat	Btu/lb	8.1
Steam Air Heater Input	Btu/lb	0.0
Effective HHV	Btu/lb	4,508

BOILER EFFICIENCY -- ACTUAL	62.9
-- ADJUSTED TO AS-FIRED HHV	63.1%

HEAT LOSS ANALYSIS	
Dry gas loss, %	13.5
Water from fuel loss, %	16.7
Moist. in air loss, %	0.3
Total losses, %	37.1

BOILER OUTPUTS	
Feed Water Flow	56,566
Blowdown flow, lb/hr	566
High press. h/out-h/in, Btu/lb	959
Blowdown : h/out-h/in, Btu/lb	198
High press. duty, Btu/hour	53,729,760
Blowdown duty, Btu/hour	112,232
Total Boiler Output, Btu/hour	53,841,992
Lb-steam/Lb-fuel	2.95
Fraction of Combustibles Burned	97.67%

BOILER FUEL, AIR, & FLUE GAS FLOW RATES	
Fuel flow rate--tons per day	228
Fuel heat input, Btu/hr	85,547,686
Fuel flow rate, lb/hr	18,976
Total air to boilers, lb/hr	125,482
Flue gas leaving boiler system, lb/hr	140,466
Air leakage, lb/hr	6,568
Thermal DeNox Carrier Air,lb/hr	0
undergrate air flow, lb/hr	83,240
overfire air flow, lb/hr	35,674
Flue gas recirculation, lb/hr	0
Flue gas leaving economizer, lb/hr	140,466
Total residue generation rate, lb/hr	4,008

The plant DCS incorporates modern combustion control algorithms and implements good combustion practice. Both the MSW feed ram and grate cycle times are modulated to maintain a set steam flow rate (nominal 51,344 lb/hr of 500 psig at 500°F). The total amount of combustion air is adjusted using the signal from an in-situ oxygen monitor located between the boiler outlet and economizer inlet. The apportioning of the air between the under- and over-fire systems is controlled by thermocouples located in the refractory wall furnace.

As MSW is burned, products of combustion evolve and pass through a steam generator and economizer. Energy is recovered in the form of steam. Dry powdered acid gas control reagent is mixed with the products of combustion at the economizer inlet via custom-designed, pneumatic rapid-dispersion lances.* The products of combustion and acid gas control reagent then pass through a high efficiency, 3-field ESP to remove entrained particulates, acid gas control reaction products and unreacted reagents. The cleaned flue gases are discharged through one side of the bi-flue stack.

Residue remaining from burning MSW is discharged from the end of the grate through a water sealed ram discharger to an enclosed ash pit. Materials that work through the grate (grate siftings) and that dropout into the boiler also discharge through the wet ash discharger. ESP ash is collected in enclosed screw conveyors and conditioned to prevent fugitive dust emissions prior to being discharged into the enclosed ash pit.

2.2 Dry Reagent Injection System Design

2.2.1 Powdered Activated Carbon [PAC] System

The portable PAC dosing system shown in Figure 2-7 was used for the testing. The PAC addition system consisted of:

- a powered hoist to raise the bag into the appropriate location over the feed hopper of the screw feeder;
- a control system to introduce fluidizing air into the bag;
- an alarm to notify personnel if the feed hopper was empty; and
- an adjustable calibrated volumetric screw feeder.

This unit allowed 900 lb. bags of PAC to be used. Signals were taken from the feeder controls to the facility control board to indicate the feeder setting. The feeder was controlled from a local station mounted on the dosing system. The hopper alarm sounded locally.

The screw feeder discharged PAC into an enclosed flexible walled pin belt conveyor shown at the bottom of Figure 2-7. This conveyor discharged through a transition chute into the throat feed tube of the venturi eductor used to entrain T-200 trona for transport to the economizer inlet shown in Figure 2-8.

* The stoichiometric trona addition rate (based on historic uncontrolled HCl and SO_2 concentrations) is 150 lb/hr. If sodium bicarbonate is used instead, the stoichiometric addition rate becomes about 110 lb/hr; the stoichiometric addition rate for hydrated lime is 90 lb/hr.

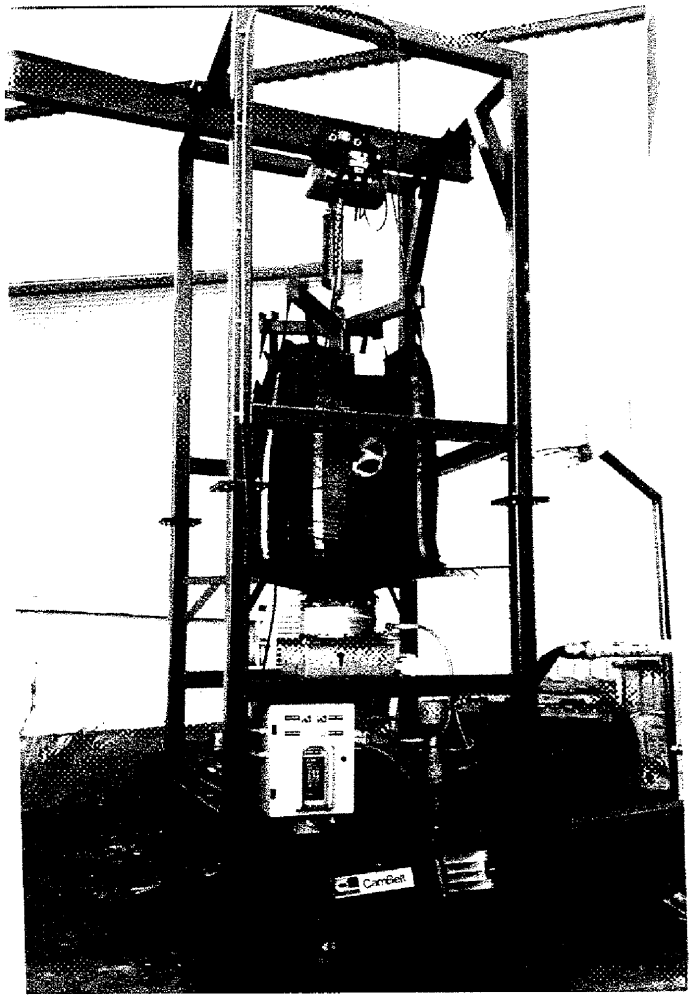

Figure 2-7 PAC dosing system.

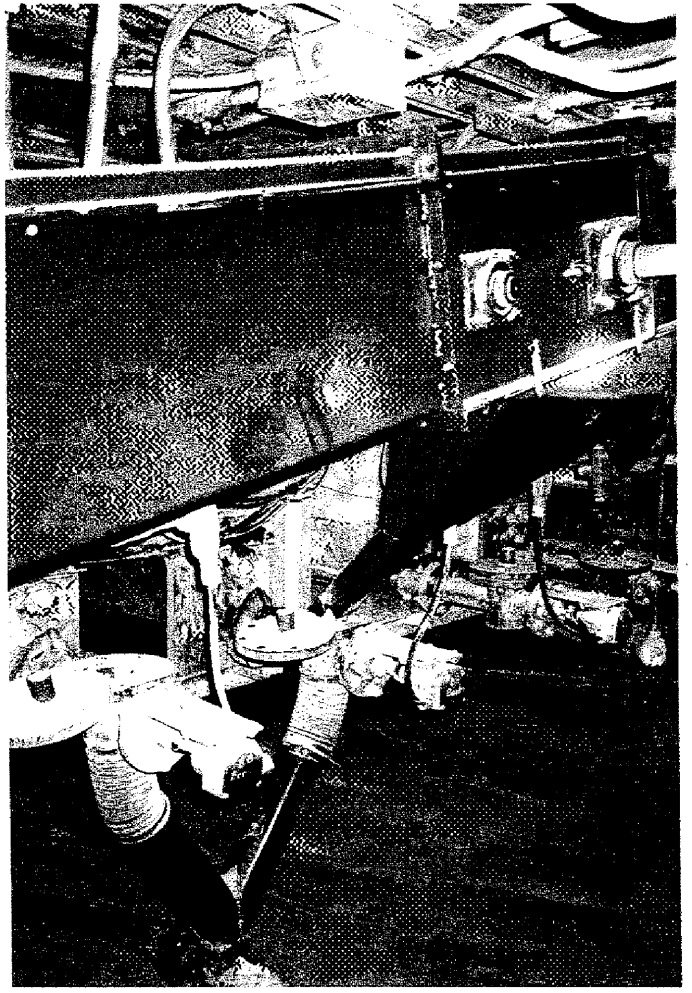

Figure 2-8 PAC discharge to the plant's trona injection system.

2.2.2 Trona System

The trona is dispersed through the rapid dispersion lance shown in Figure 2-9. This lance was fabricated out of nominal 2-inch Schedule 40 pipe. The top third of the pipe was removed and a series of 1/2 inch by 1/8 inch strips of bar stock were inserted progressively deeper to slice off equal portions of the enclosed jet and blast it into the flue gas stream. Visual observation indicates that full duct coverage is achieved in 3 to 5 feet using this lance design.

2.3 Spray Cooling System Design

The spray cooling system utilized a conventional 230 psig water pump with a recirculation loop, pressure regulator, plug type flow control valve, thermocouple and vortex shedding flow meter. In order to reduce the flue gas temperature from its normal 420°F level to 300°F, thermodynamic calculations indicate that about 9 gpm of water must be atomized between the economizer outlet and ESP inlet. The nominal 25 micron Sauter mean diameter spray needed to achieve spray evaporation prior to wall impingement dictated the use of bi-fluid nozzles. Bete Spraying Systems (SA-308) nozzles with 60° included angles were used on the ends of the water lance shown in Figure 2-10 and a single 90° nozzle (SA-308) was used in the middle. Figure 2-11 shows a disassembled nozzle.

Feed water was introduced through a ½ Schedule 40 pre-heating loop to raise the water temperature from about 80°F to 170°F at each atomizer. Increasing the water temperature reduces its viscosity which in turn produces finer hydrosols. With a feed temperature of 170°F, the hydrosal's Sauter Mean Diameter is about 70 percent of that which characterizes an 80°F spray. The air was carried through the 3-inch Schedule 40 pipe used as the main lance body. The lance spanned the duct so that it could be supported on both ends and fit through a port fabricated out of 8-inch Schedule 40 pipe with a 150 pound flange.

The spray lance was located in the duct centerline about 2 feet above the top row of serpentine economizer tubes at the location shown in Figure 2-12. The spray centerline was oriented 70° above the horizontal; 10° above the duct centerline. This orientation allows gravity to pull larger droplets down while they are still evaporating. A nozzle was set-up in a test rig outside to view the spray pattern and the droplet size. Air and water flows and pressures were below those used during plant testing. Ambient temperature was about 50°F (10°C) and the air was still. Even under these conditions, a very confined spray originated from the nozzle and was about 1 foot in diameter within 18" of the discharge. A fine mist was visible about 5 feet from the nozzle, where the plume was 2 feet in diameter. At 20 feet, the plume had spread to 3 to 5 feet in diameter, but the droplets were evaporating and the plume went to extinction. As can be seen in Figure 2-13, these nozzles produce a very fine, fog like spray.

The water sprays reduce the flue gas temperature, hence the specific volume of the flue gas. The combined effect of increased mass flow and reduced temperature is roughly a 10 percent reduction in acfm through the system while the dsftm stays constant. When particle agglomeration is induced by the trona, fly ash and PAC dust clouds passing through the spray, larger particles are formed. These can settle on the bottom of the breaching shown to the upper left of Figure 2-12. The average gas velocity downstream of the economizer is only 90 percent of previous values, so there is the potential for more fly ash, trona and PAC sedimentation in the breaching leaving the economizer than previously experienced.

The reduced gas volume also increases the SCA of the ESP from 389 (under MCR conditions) to about 430 Ft^2/1,000 acfm at a flue gas temperature of 300°F.

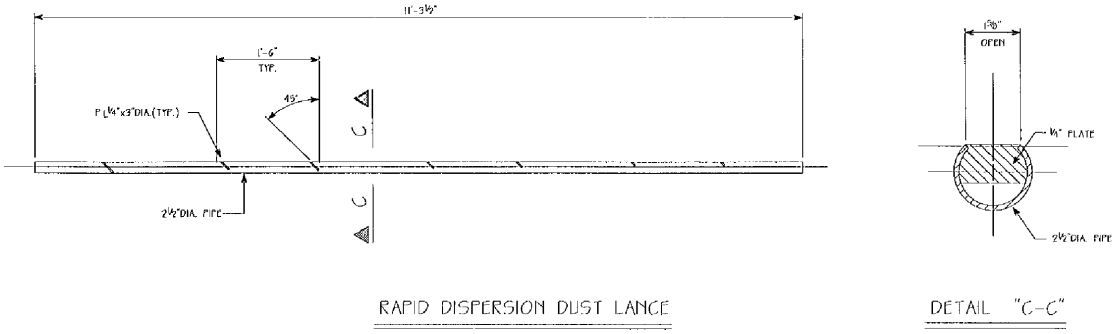

Figure 2-9 Rapid dry reagent dispersion lance design.

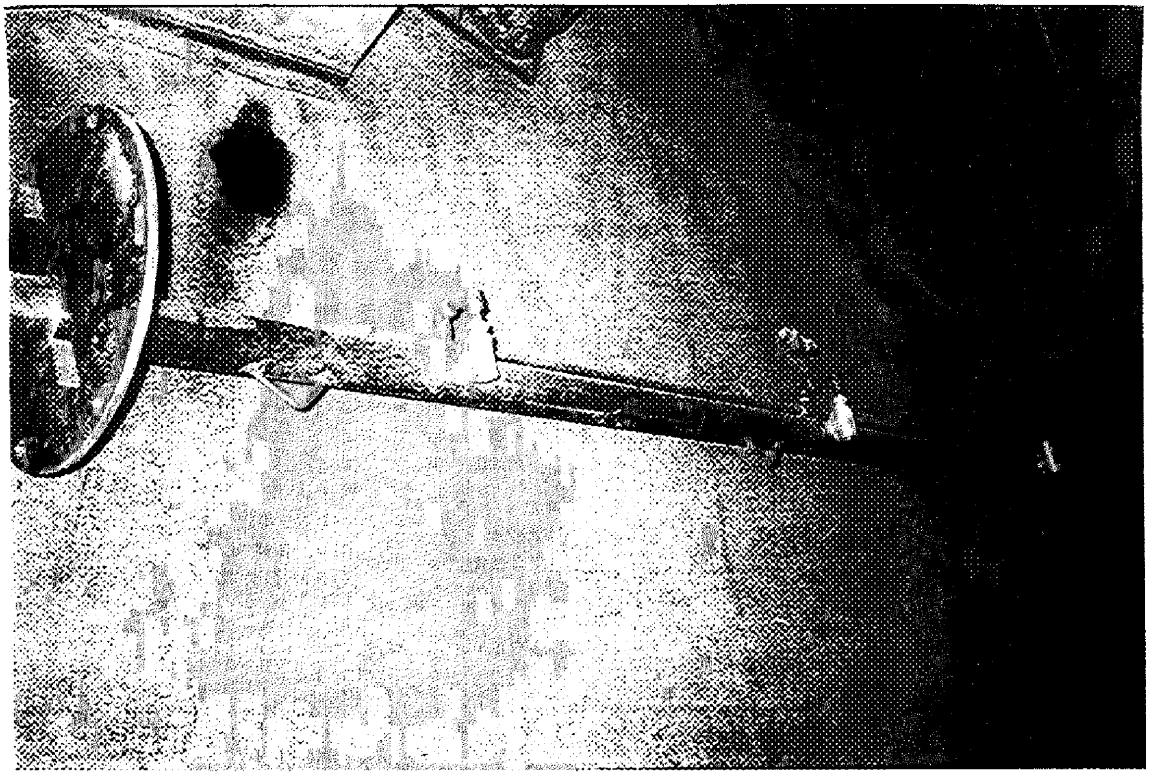

Figure 2-10 Spray lance without the nozzles attached.

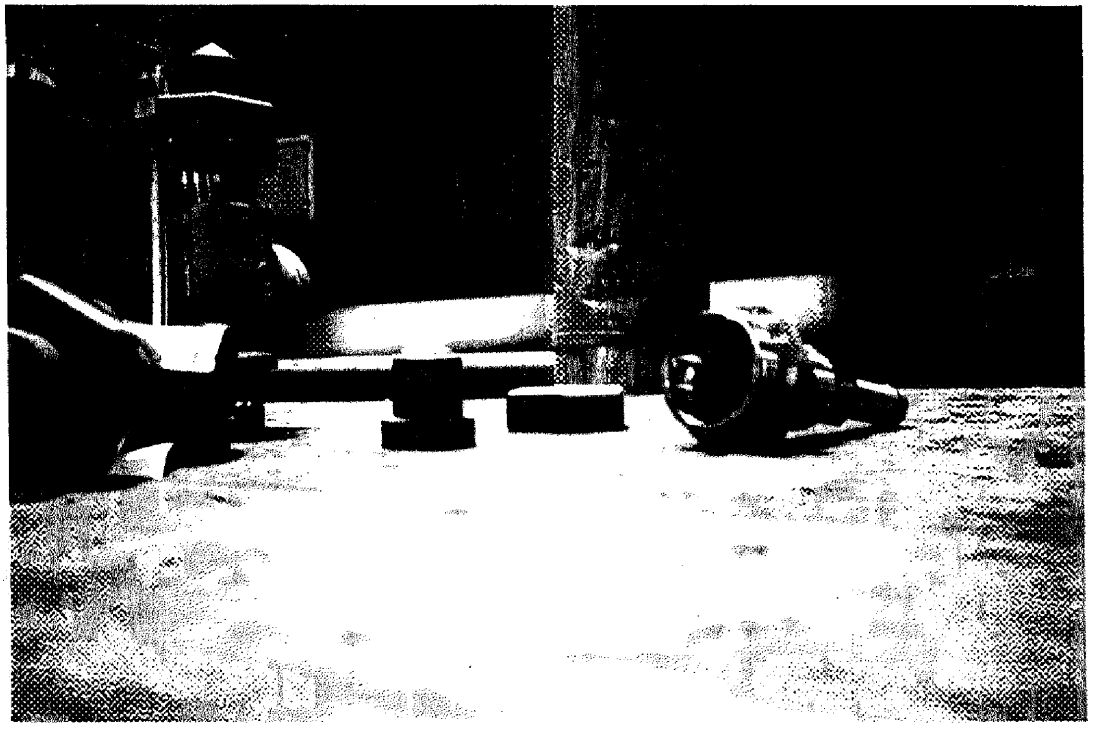

Figure 2-11 Disassembled spray nozzle.

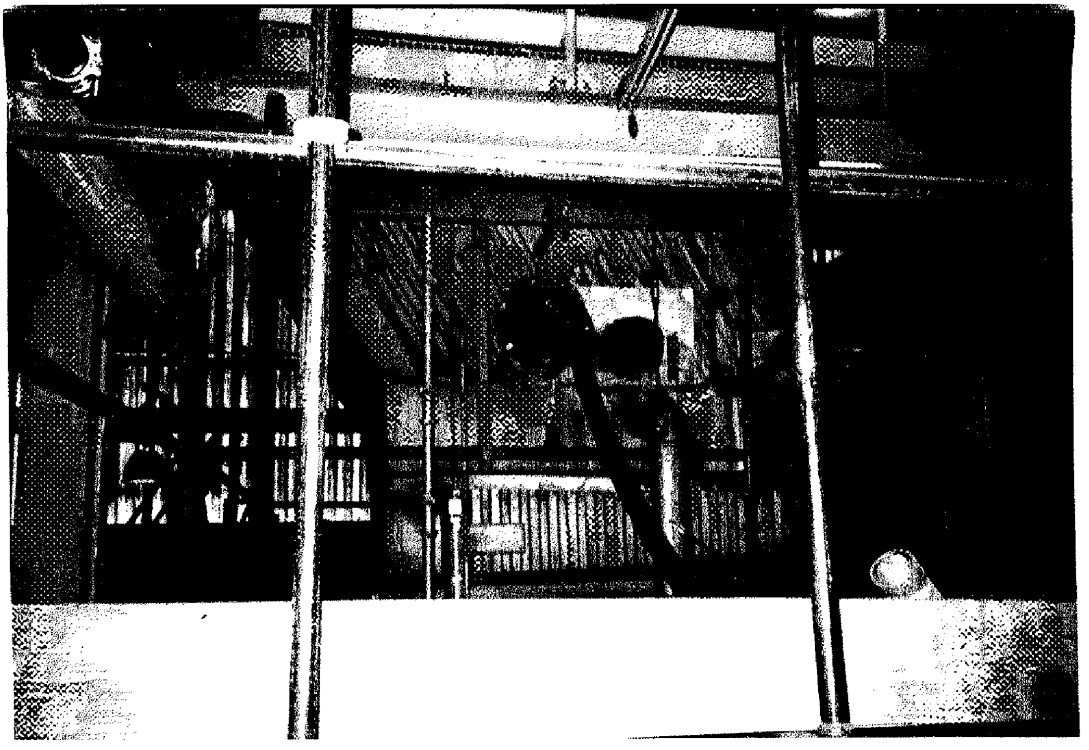

Figure 2-12 Spray lance inserted into the duct with air and water hose connections made.

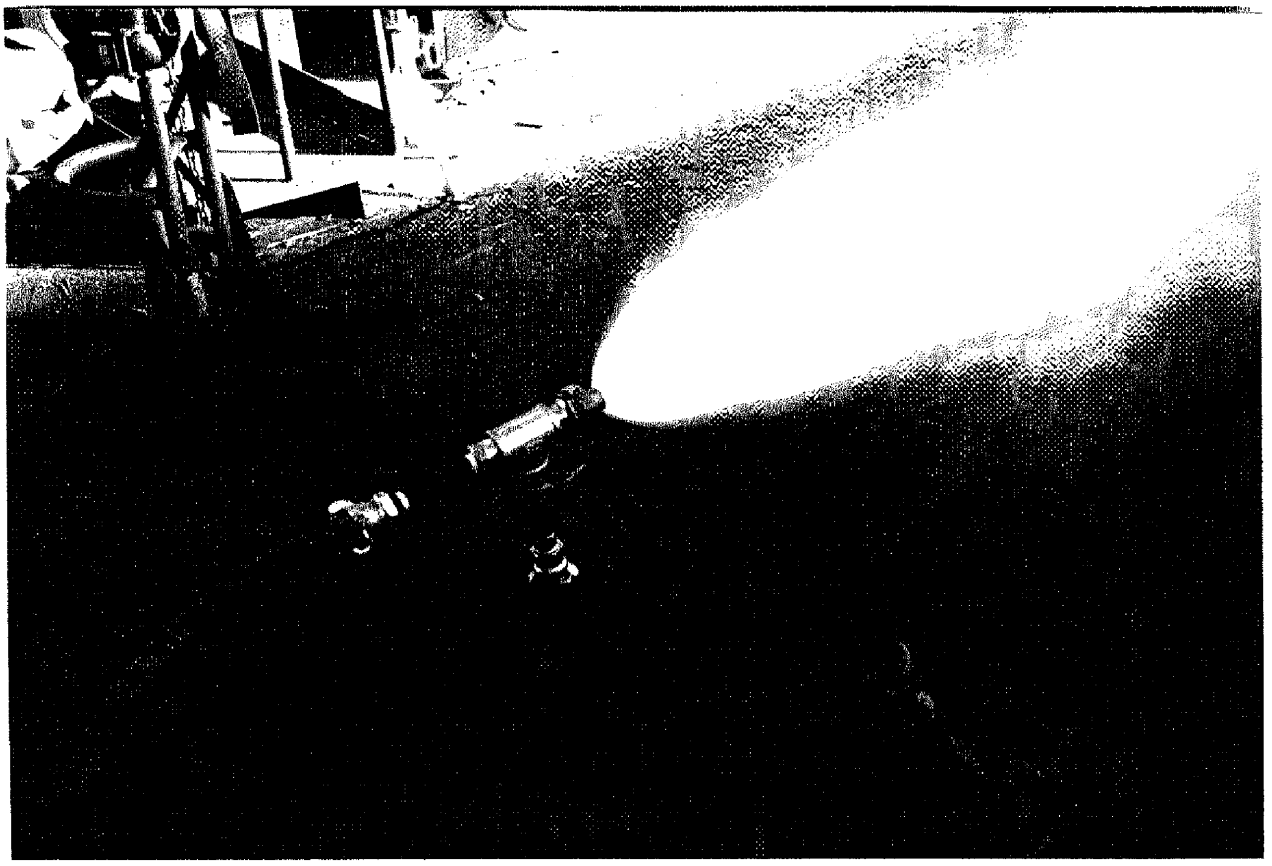

Figure 2-13 Atomizer spray pattern showing air (at rear) and water (at bottom) connections.

SECTION 3—RESULTS & DISCUSSION

The proof-of-concept demonstration testing began on November 17, 1995 and concluded on November 28, 1995. The testing sequence was randomized and generally followed the planned test matrix. Delays in getting the water spray system activated caused the planned no-trona, no-PAC test to be done under normal ESP temperature conditions (420°F) rather than at the planned 350°F. An extra, but unplanned temperature condition (325°F) was achieved towards the end of the testing when planned 300°F temperatures could not be maintained.

Within the normal limitations of such programs, the results presented and discussed in this section show that temperature control combined with PAC addition allow facilities equipped with ESPs to meet new PCDD/F and mercury emission limitations. Similarly, small (<250 TPD MWC) facilities can meet the required acid gas reduction standards; however, the results show limited success in meeting large facility acid gas emissions limits.

3.1 Combustion System Performance

Plant instrument readings were used to establish that the test unit was operating in a normal manner throughout testing. Box plots and key plant data are provided in Appendix B. Both the *in situ* (boiler outlet) and stack oxygen meters show similar averages and ranges for each nominal 4-hour test. CO concentrations were also comparable across all test conditions. Plant CEMS recorded stack NO_x and SO_2 for the other unit ("A") that were similar to those of the test unit ("B") measured with the test team's CEMS. Opacity was generally constant throughout testing with an indication of reduced levels during some periods when the water sprays were in use.

Average trona flow was held within one percent of the 150 lb/hr[1] (nominal 2,000 mg/dsm^3 @ 7% O_2) set point for all runs. A brief 15 to 30 minute excursion down to 130-140 lb/hr occurred in some runs which is a data logging artifact. When the trona weigh bin is filled, the feed screw speed remains constant, but data are lost for 1-3 minutes. When these zeros are averaged into the 15-minute average, a dip in injection ratio is indicated.

Steam flow was about 105 percent of MCR (54,000 lb/hr vs. 51,344 lb/hr) at constant design temperature and pressure for all runs; steam flow was reduced for about a half hour during both runs 19 and 21. The system draft control transmitter was replaced at the beginning of run 15; all furnace and ESP draft data since that time showed normal variability and were within the range of the data taken for the week following the test. Fireside temperatures along the entire gas path were within the normal range and constant for all periods. The ambient temperature, however, was lower for runs 18 through 23 than for the testing conducted earlier in the week and the relative humidity was about 10 percent higher than the 25 percent that characterized earlier testing.

3.2 Observed Emissions Control System Performance

Manual method and continuous emissions monitor results were taken at the stack. Table 3-1 is a summary of the individual run results expressed in regulatory units, corrected to 7% O_2, for pollutants listed in Section 129 of the Clean Air Act. The results for additional metals, halogen and organic pollutants measured

[1] DSI systems are likely to be regulated just like PAC with hourly average (lb/hr) and quarterly utilization rates reported under 40 CFR 60, subpart Cb.

Table 3-1 Measured Section 129 pollutant characteristics

								all @ 7% O2						Stack		PPMdv @ 7% O2				all at 7% O2				
		TRONA		PAC		O2	CO2	CO	SO2-24 hr geo		NOx-24	THC	Opacity	TEMP	FLOW	HF	Cl2	HCl		TSP	Cd	Pb	Hg	TOTDXN
DATE	TEST I.D.	lb/h	mg/dsm3	lb/h	mg/dsm3	%	%	ppm_{dv}	ppm_{dv}	Eff	ppm_{dv}	ppm_{dv}	%	Deg F	DSm3/hr				Eff	mg/dsm3	$\mu g/dsm^3$	$\mu g/dsm^3$	$\mu g/dsm^3$	ng/dsm^3
951117	T01	150	1,938	0	0	10.9	9.5	56	96	11%	269	2.0	2.4	417	48,810	3.1	0.8	340	27%	20.5	18	249	155	116
951117	T02(HCl)	150	1,980	0	0	10.9							2.4			3.0	0.7	341	27%					
951118	T02	150	2,065	0	0	11.1	9.1	70	41	62%	256	1.5	2.3	417	46,731	(2.6)	(0.4)	193	59%	9.4	12	293	92	91
951118	T03	150	2,008	0	0	10.8	9.4	83	43	60%	227	1.2	2.4	408	46,622	(2.5)	3.3	158	66%	12.4	14	485	247	87
951119	T04	150	1,994	27	359	11.0	9.3	62	62	43%	227	0.9	2.2	412	47,917	7.7	(0.4)	300	36%	5.5	16	163	60	37
951119	T05	150	1,960	27	353	10.9	9.2	69	49	55%	236	1.1	2.2	414	48,252	3.0	1.6	252	46%	6.9	17	170	43	15
191120	T06	0	0	0	0	10.3	9.6	42	131		242	0.7	1.7	408	45,283	2.5	(0.1)	542		6.7	16	168	145	115
951120	T07	0	0	0	0	10.4	9.7	52	85		236	0.6	1.8	389	43,249	3.3	3.0	394		2.9	9	82	69	98
951121	T08	150	2,011	27	361	10.3	10.0	48	41	62%	242	1.0	2.0	346	44,407	2.4	0.05	221	53%		4	60	20	20
951121	T09	149	2,090	27	374	10.7	9.4	70	37	66%	223	0.1	2.3	353	44,151	(2.4)	(0.03)	260	44%		6	141	24	17
951122	T10	151	2,041	27	365	11.0	9.3	70	46	57%	499	0.6	2.9	296	47,037	2.8	(0.04)	196	58%	2.6	11	100	1,037	154
951122	T11	150	1,989	31	416	10.7	9.5	63	34	69%	215	1.2	3.0	304	46,715	(2.4)	(0.03)	139	70%	6.3	12	103	22	6.0
951123	T12	151	1,995	0	0	10.7	9.6	63	53	51%	260	0.5	2.8	302	46,667	2.5	(0.04)	170	64%	2.5	7	115	104	151
951123	T13	150	2,033	0	0	11.1	9.0	61	56	48%	270	1.8	3.1	305	47,382	2.7	0.08	177	62%	0.9	9	102	258	127
951124	T14	150	1,920	27	345	10.7	9.4	78	42	61%	259	0.2	2.0	348	48,367	3.5	(0.04)	399	15%	0.2	7	126	22	7.4
951124	T15	150	1,925	27	347	10.5	9.5	58	51	53%	264	0.8	2.5	350	47,105	(2.4)	0.10	175	63%	5.0	9	110	22	3.4
951125	T16	150	1,902	20	251	10.6	9.5	84	53	51%	353	1.2	2.3	349	48,285	(2.4)	0.05	174	63%	1.3	7	112	20	5.3
951125	T17	150	2,057	19	261	10.7	9.5	70	48	56%	251	1.1	2.7	347	45,059	(2.5)	0.07	141	70%	5.8	133	183	25	4.5
95126	T18	150	1,939	0	0	10.0	10.1	60	48	56%	219	0.3	2.1	342	44,791	3.0	0.06	148	68%	4.6	6	104	89	83
95126	T19	150	2,050	0	0	10.4	9.7	97	34	69%	216	3.0	2.1	345	43,969	11.1	0.3	160	66%	4.0	8	220	202	250
951127	T20	149	1,967	19	253	10.3	9.7	50	46	57%	241	0.4	2.1	318	45,137	(2.4)	0.6	169	64%	2.0	58	80	22	12
951127	T21	150	1,964	20	259	10.5	9.5	101	25	77%	249	5.1	2.1	319	46,290	2.6	0.3	257	45%	7.6	90	111	17	11
951128	T22	150	2,204	27	397	10.9	9.2	62	36	67%	233	0.5	1.7	323	42,920	(2.5)	0.3	247	47%	30	262	146	17	3.0
951128	T23	150	1,975	27	356	10.0	10.1	56	52	52%	237	0.7	1.9	330	43,924					20	16	210	15	3.3
951118	blank-1 (glass)																			0.6	(0.40)	12	2.36	0.1
951126	blank-2(quartz)																			-0.7	(0.44)	(4.4)	(0.04)	0.3
951129	blank-3(quartz)																			0.4	(0.41)	(4.1)	(0.04)	0.4
	Detection Limit																			2.0				0.4
	Limit of Quantification																			6.8				1.3

notes: PAC was interupted flow during T10. The actual PAC addition rate may have been zero for this run.
A glass filter was used during T15 instead of a quartz filter. Lead and Mercury are back ground corrected.
A mercury sample was not separated from the probe rinse for run T15, result may be 10 percent low.
Parentheses identify the detection limit for below detection limits results.
Underlining indicates runs and values discussed above

during the test program are provided in Appendix A, but they are not discussed in this report. Others are encouraged to utilize and interpret these results.

Table 3-2 is a summary of historic testing results for DCERF. A comparison indicates that uncontrolled SO_2, NO_x and CO emissions are similar to those observed during this test program. The historic HCl measurements employed a variety of techniques (specific ion electrode, titration and dilution-probe CEMS) so the results are neither directly comparable to each other nor necessarily to regulatory standards. The uncontrolled HCl concentrations measured during this test program are similar to preliminary results from another, as yet unpublished, study at the facility.

Pollutant-by-pollutant results are discussed in the following subsections.

3.2.1 PCDD/F Air Emissions Reductions

PAC addition has a pronounced effect on PCDD/F concentrations. Figure 3-1 is a summary of the total PCDD/F test results and includes individual run removal efficiencies and a plot of calculated emission limitations that will be met with 95 percent confidence by the average of each annual three-run compliance test conducted over a five year period. PCDD/F removal efficiencies assume that the average PAC-free dioxin concentration is representative.

PAC and trona injection rates are reported in nominal units since plants typically control injection rates on mass flow rather than flue gas concentrations. Actual reagent concentrations are provided in Table 3-1. 150 lb/hr of trona is nominally 2,000 mg/dsm^3 @ 7% O_2. 15 and 30 lb/hr of PAC are 200 and 400 mg/dsm^3 @ 7% O_2 respectively.

Historic uncontrolled dioxin concentrations measured at DCERF have been on the order of 300 ng/dsm^3 @ 7% O_2. Individual values measured during the test program without PAC addition ranged from 83 to 250 ng/dsm^3 @ 7% O_2. Injecting both 15 and 30 lb/hr of PAC, nominally 200 and 400 mg/dsm^3 @ 7% O_2, caused an average 90 percent reduction in PCDD/F concentrations. When the data were fit to the Langmuir isotherm based equation, the one data point that was a visual outlier was confirmed to be an outlier. The outlier is Run 10 when 30 lb/hr of PAC was supposed to be injected, but field observations had indicated that the flow may have been zero.

Excluding run 10, the balance of the data are adequately described by the equation ($r = 0.55$; significant at the 90 percent confidence level). The results presented in the plot in Figure 3-1 represent the estimated upper prediction limit of data that contains the results of the next five sets of triplicate tests. As such, they incorporate the observed variability in the data (process and test method). Emissions limitations are a more appropriate measure of probable performance than test averages since averages are likely to be exceeded half the time and statistically derived emissions limitations represent the lowest level prudent people incorporate into operating permits.

The reduced results indicate that there is no major difference in calculated emissions limitations when either 200 or 400 mg/dsm^3 @ 7% O_2 of PAC is injected. There is a fairly significant temperature effect which indicates temperatures below 350°F are preferred. Operating below 350°F should provide a comfortable margin between the 60 ng/dsm^3 @ 7% O_2 guideline emissions limitation for large ESP equipped MWCs and expected performance.

Table 3-2 Historic Section 129 emissions test results for DCERF.

RUN	DATE (YYMMDD)	REAGENT TYPE	REAGENT FLOW Lb/hr	STACK TEMP (°F)	Particulates mg/dsm^3 @7% O2	SO_2 PPMdv @7% O2	NO_x PPMdv @7% O2	CO PPMdv @7% O2	F mg/m3 @7% O2	HCl PPMdv @7% O2	Pb mg/m3 @7% O2	Hg mg/m3 @ 7% O2	TOTDXN ng/m3 @ 7% O2
UNIT A													
A-10-1	930319	LIME	153	381				96					
A-10-2	930319	LIME	113	381				103					
A-10-3	930319	LIME	108	374				130					
A-101A-1	930428	LIME	132	387								0.419	
A-101A-2	930428	LIME	136	396								0.068	
A-101A-3	930428	LIME	138	382								0.001	
A-12-1	930901	TRONA	227	356	*129*			77			*3.809*		
A-12-1	930428	LIME	137	419							1.353		
A-12-2	930901	NONE	0	336	10			91			*0.132*		
A-12-2	930429	LIME	118	432							1.665		
A-12-3	930902	TRONA	127	382	23			84			0.061		
A-12-3	930429	LIME	95	419							2.306		
A-12-4	930902	TRONA	119	342	16			74			0.205		
A-13B-1	930623	TRONA		415					0.11				
A-13B-2	930623	TRONA		420					0.11				
A-13B-3	930623	TRONA		401					0.12				
A-26-1	930319	LIME	124	404						255			
A-26-2	930319	LIME	160	402						416			
A-26-3	930319	LIME	111	402						499			
A-5-1	930318	LIME		384	26								
A-5-2	930318	LIME	82	420	31								
A-5-3	930319	LIME	121	415	31								
A-6C-1	930318	LIME	70	378		40	298						
A-6C-1	930902	TRONA	138	409		88	330	84		135			
A-6C-2	930318	LIME	132	376		57	364						
A-6C-2	930902	TRONA	114	342		77	339	73		34			
A-6C-3	930319	LIME	121	372		53	251						
A-6C-3	930903	TRONA	119	341		72	380	74		18			
A-DEW 8-10	911002	LIME	125	375		119				480			
A-DEW 8-11	911002	NONE	0	371		111				323			
A-DEW 8-12	911002	LIME	131	365		65				864			
A-DEW 8-13	911002	NONE	0	380		137				491			
A-DEW 8-14	911003	LIME	123	377		45				177			
A-DEW 8-15	911003	NONE	0	383		87				326			
A-DEW 8-16	911003	LIME	136	364		112				891			
A-DEW 8-17	911003	NONE	0	372		89				290			
A-DEW 8-18	911004	LIME	119	375		99				271			
A-DEW 8-19	911004	NONE	0	364		114				166			
A-DEW 8-2	910930	LIME	122	367		185				247			
A-DEW 8-20	911004	LIME	124	372		68				238			
A-DEW 8-21	911004	NONE	0	375		136				426			
A-DEW 8-3	910930	NONE	0	372		139				697			
A-DEW 8-4	910930	LIME	114	376		77				229			
A-DEW 8-5	910930	NONE	0	376		169				1363			
A-DEW 8-6	911001	NONE	0	375		104				691			
A-DEW 8-7	911001	LIME	134	380		74				300			
A-DEW 8-8	911001	NONE	0	370		152				405			
A-DEW 8-9	911001	LIME	134	381		72				361			
A-HCL #1	880212	LIME	174	453						596			
A-HCL #1	880409	LIME	127	415					0.66	63			
A-HCL #2	880216	LIME	174	440	29		259			379			
A-HCL #2	880216	LIME	174	440			246						
A-HCL #2	880216	LIME	174	440			225						
A-HCL #2	880216	LIME	174	440			329						
A-HCL #2	880409	LIME	127	419					0.48				
A-HCL #3	880213	LIME	174	430	23		217			307			
A-HCL #3	880213	LIME	174	430			204						
A-HCL #3	880213	LIME	174	430			209						
A-HCL #3	880213	LIME	174	430			239						
A-HCL #3	880409	LIME	127	408					0.67				
A-HG #1	880408	LIME	127	419								0.022	
A-HG #2	880408	LIME	127	406								0.038	
A-HG #3	880409	LIME	127	392									
A-HG #4	880410	LIME	127	406								0.242	
A-PB #1	880409	LIME	127	410							0.024		
A-PB #2	880409	LIME	127	399							0.884		
A-PB #3	880409	LIME	127	400							1.330		
A-SO2 #1	880213	LIME	174	432	46	77	76						

Table 3-2 Historic Section 129 emissions test results for DCERF (Cont'd).

RUN	DATE (YYMMDD)	REAGENT TYPE	REAGENT FLOW Lb/hr	STACK TEMP (°F)	Particulates mg/dsm^3 @7% O2	SO_2 PPMdv @7% O2	NO_x PPMdv @7% O2	CO PPMdv @7% O2	F mg/m3 @7% O2	HCl PPMdv @7% O2	Pb mg/m3 @7% O2	Hg mg/m3 @ 7% O2	TOTDXN ng/m3 @ 7% O2
A-SO2 #1	880213	LIME	174	432			194						
A-SO2 #1	880213	LIME	174	432			378						
A-SO2 #1	880213	LIME	174	432			86						
A-SO2 #1	880408	LIME	127	425		164							
A-SO2 #2	880214	LIME	174	440		325		92					
A-SO2 #2	880408	LIME	127	397		159							
A-SO2 #3	880214	LIME	174	430		162		130					
A-SO2 #3	880408	LIME	127	408		184							
A-EPA23-1	931130	TRONA	115	415									357
A-EPA23-2	931201	TRONA	115	408									311
UNIT B													
B-10-1	930623	TRONA		368				106					
B-10-2	930623	TRONA		370				95					
B-10-3	930623	TRONA		371				113					
B-101B-1	930622	TRONA		393								0.174	
B-101B-2	930622	TRONA		386								0.145	
B-101B-3	930622	TRONA		383								0.009	
B-12-1	930831	TRONA		342	18			94			0.133		
B-12-1	930429	LIME	129	346							0.830		
B-12-2	930831	TRONA		345	14			77			0.064		
B-12-2	930429	LIME	126	369							0.839		
B-12-3	930831	TRONA		345	12			75			0.605		
B-12-3	930429	LIME	124	385							2.033		
B-13B-1	930506	LIME	126	395					0.33				
B-13B-2	930506	LIME	70	392					0.08				
B-13B-3	930506	LIME	122	390					0.08				
B-26-1	930623	TRONA		382						386			
B-26-2	930624	TRONA		369						424			
B-26-3	930624	TRONA		388						627			
B-5-1	930428	LIME	135	387	51								
B-5-2	930428	LIME	136	390	29								
B-5-3	930428	LIME	139	391	30								
B-6C-1	930428	LIME	137	361		48	286						
B-6C-1	930901	TRONA	75	408		85	366	73		2			
B-6C-2	930429	LIME	118	357		63	272						
B-6C-2	930901	TRONA	227	342		111	342	81		20			
B-6C-3	930429	LIME	102	359		53	264						
B-6C-3	930901	TRONA	255	341		74	309	80		5			
B-DEE 8-10	911002	LIME	115	394		36				1200			
B-DEE 8-11	911002	NONE	0	392		85				965			
B-DEE 8-12	911002	LIME	123	399		35				351			
B-DEE 8-13	911002	NONE	0	390		87				581			
B-DEE 8-14	911003	LIME	119	392		36				464			
B-DEE 8-15	911003	NONE	0	390		68				718			
B-DEE 8-16	911003	LIME	131	392		93				418			
B-DEE 8-17	911003	NONE	0	392		96				1025			
B-DEE 8-18	911004	LIME	138	397		11				528			
B-DEE 8-19	911004	NONE	0	375		61				305			
B-DEE 8-2	910930	LIME	113	407		50				354			
B-DEE 8-20	911004	LIME	138	392		30				452			
B-DEE 8-21	911004	NONE	0	390		129				1430			
B-DEE 8-3	910930	NONE	0	404		98				1196			
B-DEE 8-4	910930	LIME	107	403		48				411			
B-DEE 8-5	910930	NONE	0	399		463				4115			
B-DEE 8-6	911001	NONE	0	385		166				531			
B-DEE 8-7	911001	LIME	123	400		44				573			
B-DEE 8-8	911001	NONE	0	394		130				561			
B-DEE 8-9	911001	LIME	125	399		60				371			
B-HCL #1	880409	LIME	87	436					1.07	205			
B-HCL #2	880409	LIME	87	468					1.34				
B-HCL #3	880409	LIME	87	448					1.44				
B-HG #1	880408	LIME	87	434								0.116	
B-HG #2	880408	LIME	87	429								0.997	
B-HG #3	880409	LIME	87	423								0.242	
B-HG #4	880410	LIME	87	453								0.182	
B-PART #1	880218	LIME	174	494	38								
B-PART #2	880218	LIME	174	489	37								
B-PART #3	880218	LIME	174	481	21								

Table 3-2 Historic Section 129 emissions test results for DCERF (Cont'd).

RUN	DATE (YYMMDD)	REAGENT TYPE	REAGENT FLOW Lb/hr	STACK TEMP (°F)	Particulates mg/dsm^3 @7% O2	SO_2 PPMdv @7% O2	NO_x PPMdv @7% O2	CO PPMdv @7% O2	F mg/m3 @7% O2	HCl PPMdv @7% O2	Pb mg/m3 @7% O2	Hg mg/m3 @ 7% O2	TOTDXN ng/m3 @ 7% O2
B-PB #1	880409	LIME	87	436							1.269		
B-PB #2	880409	LIME	87	446							0.624		
B-PB #3	880409	LIME	87	456							1.484		
B-SO2 #1	880408	LIME	87	434		59							
B-SO2 #2	880408	LIME	87	422		67							
B-SO2 #3	880408	LIME	87	423		49							
B-EPA23-3	931202	TRONA	127	390									227

Note: Underlined and italicized data are known to be non-representative.

Total Dioxins -- ng/dsm3 @ 7% O2						
Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	115 98				107
150	0	116 91 87	83 250		151 127	129
150	15		5.3 4.5	12 11		8.3
150	30	37 15	20 17 7.4 3.4	3.0 3.3	6.0 154	13
average		80	49	7.4	95	57

Note: Underlined values excluded from averages.

Total Dioxin Removal Efficiency						
Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0					
150	0					
150	15		97% 97%	92% 93%		95%
150	30	76% 90%	87% 89% 95% 98%	98% 98%	96% 2%	94%
average		83%	94%	95%	96%	95%

Note: Underlined values excluded from averages.

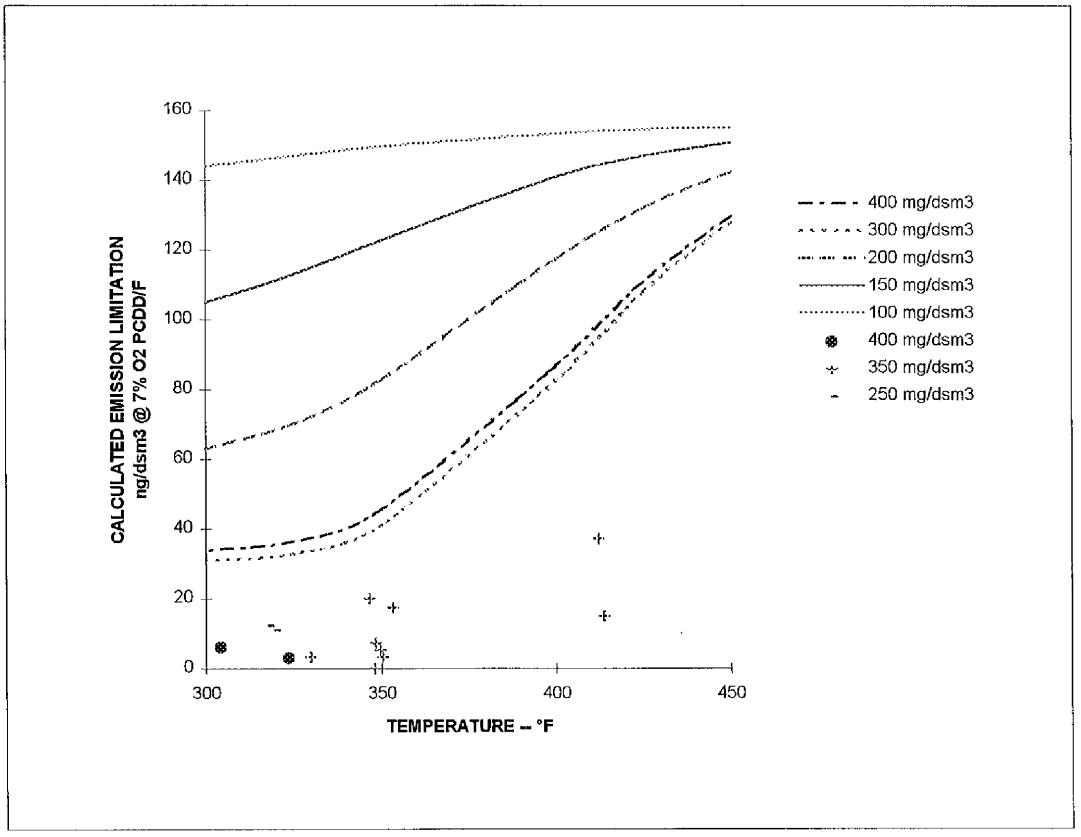

Figure 3-1 PCDD/F emissions test results and calculated emission limitations.

There is a substantial flaring of the emissions limitations as the amount of PAC injected is reduced. The mathematical formulation used to estimate emissions limitations described in Section 5 considers both the lack of fit between the data and model and the distance between tested and extrapolated conditions. Since most of the PAC testing was done at 30 lb/hr (400 mg/dsm^3 @ 7% O_2), the statistically derived limit is slightly inflated at 15 lb/hr (200 mg/dsm^3 @ 7% O_2) addition rates. At lower injection rates, it is further inflated. Consequently, lower limits may be routinely achievable. But the available data do not support lower emissions limitation projections.

While the efficiency, hence outlet concentration, calculations can be substantially "improved" by using the high or low uncontrolled PCDD/F concentration instead of the uncontrolled average to reduce the variability and improve the fit of the Langmuir type equation, this approach is not recommended. The average is the best point estimate for a data set. Also, there is no way for anyone to know what the uncontrolled PCDD/F concentration would have been for any individual run since that concentration was not, and could not have been, measured since the acts of reducing temperature and injecting reagents alter the emitted concentrations.

The presence or absence of trona did not affect PCDD/F concentrations. Also, while temperature has some effect, it was not as pronounced as expected based on Figure ES-1. In fact, the 420°F results seem to be essentially the same as those characterizing lower temperature operation. This could point toward a shift in mechanism. Most likely, however, this is simply the result of data variability, sometimes called noise.

Figure 3-2 is a dendrogram summarizing the results of the PCDD/F isomer and homologue profiles by grouping the runs together in terms of nearest neighbors. In addition to the test results from this demonstration test, the three historic PCDD/F runs for DCERF are included to provide perspective. The labels summarize the test operating condition. The first three digits are the lb/hr of trona injected; the next two are the lb/hr of PAC added; and the last three are the flue gas temperature.

A number of interesting observations can be made from the resulting pattern, but these must be taken as tentative since the data are comparatively noisy (i.e., has a high variability). The data clusters into three well separated groups. One group has all but one of the PAC runs. The separated run is number 10 which was identified as probably run without PAC. Thus, the signature analysis confirms this was a PAC-free test condition. A second group has most of the remainder of these tests. The third group contains the historic runs plus one run from this test series. Different APCS temperature results scatter throughout the three groups; hence, temperature control may affect total emitted concentrations, but it does not affect the isomer and homologue distribution (i.e., the mixtures are the same). The trona-free and DSI operational run conditions are intermixed so it was concluded that acid gas control does not affect the character of the dioxins emitted. The overall implication of these findings is that PAC decreases the relative toxicity of the residual PCDD/F—the ratio of total PCDD/F to ITEQ increases—indicating preferential removal of PCDD/F isomers with chlorine atoms in the 2,3,7, and 8 positions.

3.2.2 Mercury Air Emissions Reductions

PAC addition produced pronounced reductions in mercury emissions. Figure 3-3 is a summary of measured mercury emissions, removal efficiencies and a plot of emissions limitations likely to be achieved with various levels of PAC addition and operating temperatures. Like all the figures in this section, the plot represents the maximum 3-run average likely to be encountered over 5 sequential triplicate test series. Similar to the PCDD/F results, the PAC addition rate for Run 10 was observed to be uncertain in the field. The analytic results indicate that mercury emissions for this run are comparable to uncontrolled emissions.

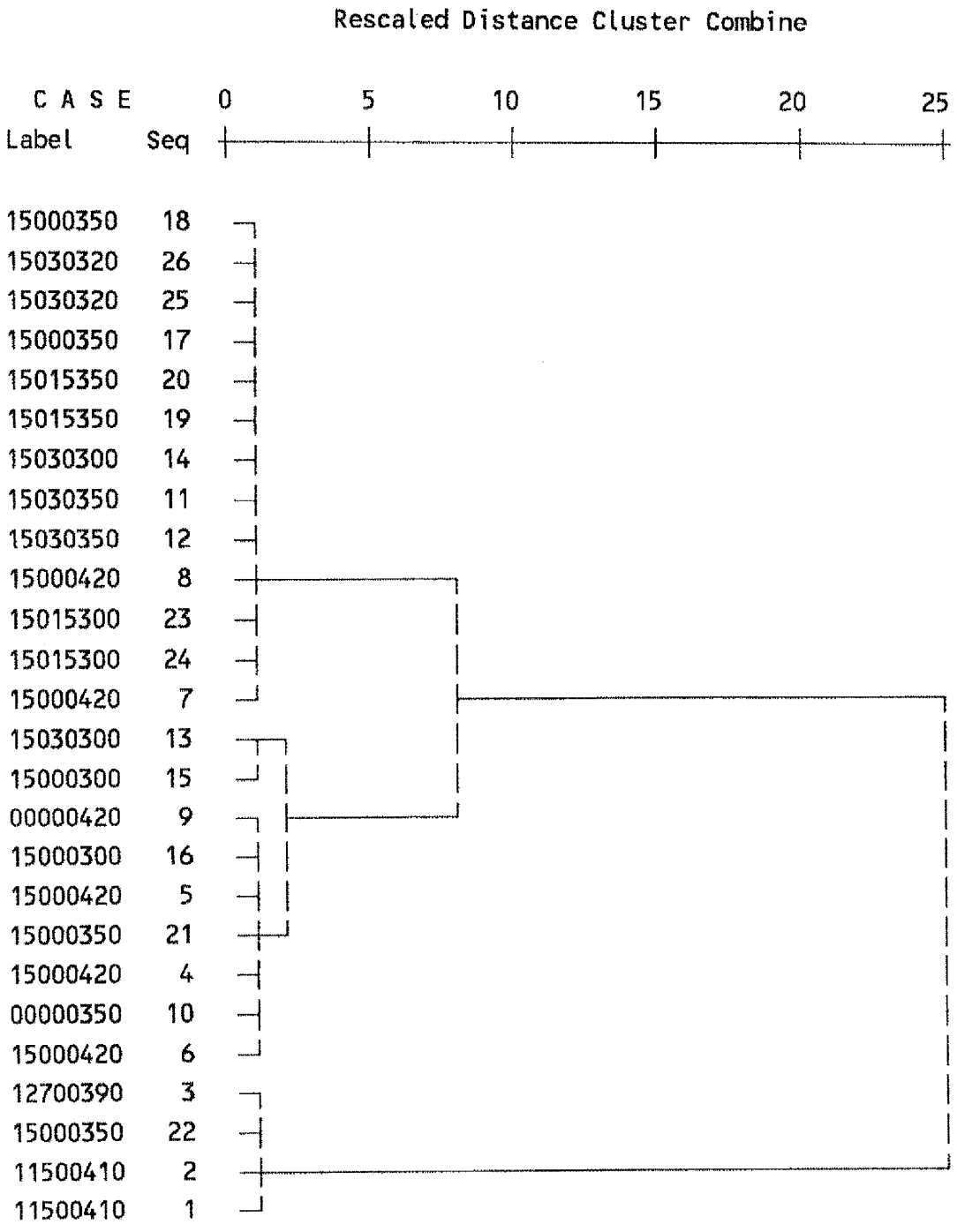

Figure 3-2 Dendogram comparing the PCDD/F signatures.

Mercury -- ug/dsm3 @ 7% O2						
Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	145 69				107
150	0	155 92 247	89 202		104 258	164
150	15		20 25	22 17		21
150	30	60 43	20 24 22 22	17 15	22 296	54
average		116	53	18	170	86

Note: Underlined values excluded from averages.

Total Mercury Removal Efficiency						
Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0					
150	0					
150	15		90% 87%	89% 91%		89%
150	30	69% 78%	90% 88% 89% 89%	91% 92%	88% -53%	94%
average		74%	89%	91%	88%	95%

Note: Underlined values excluded from averages.

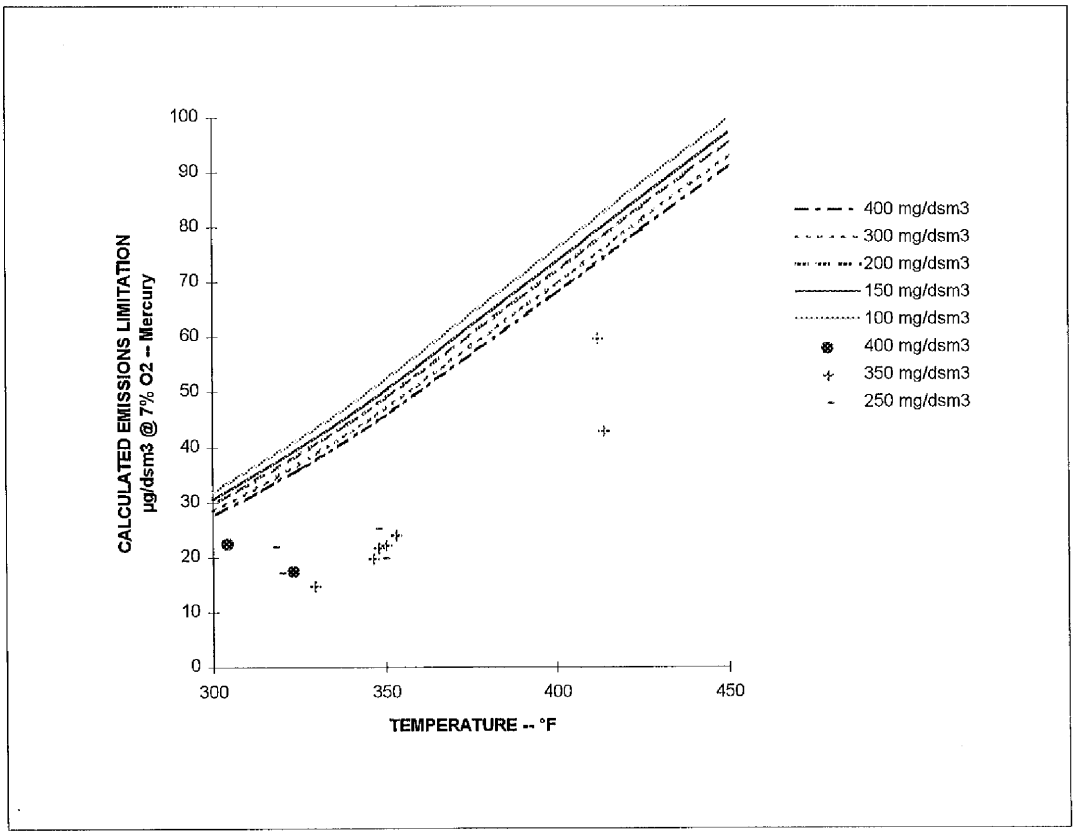

Figure 3-3 Mercury emissions test results and calculated emission limitations.

Further, when distribution of mercury throughout the Method 29 train is considered, the characteristics of run 10 are like those of uncontrolled emissions shown at the top third of Table 3-3. Consequently, this run was not included in the development of emission limitations likely to be met during annual testing throughout the five year validity period of a Title V operating permit.

Table 3-3 Distribution of mercury in the Method 29 sampling train.

DATE	RUN	TRONA	PAC	Tstack	Mercury Distribution			Mercury
		lb/hr	lb/hr	°F	Front Half	Back Half	Permanganate	µg/dsm^3
951120	T06	0	0	408	0.20%	98.50%	1.30%	145
951120	T07	0	0	389	0.10%	93.70%	6.10%	69
951117	T01	1,938	0	417	0.20%	97.80%	2.00%	155
951118	T02	2,065	0	417	0.20%	95.50%	4.40%	92
951118	T03	2,008	0	408	3.00%	92.40%	4.60%	247
951126	T19	2,050	0	345	2.50%	91.40%	6.10%	202
951126	T18	1,939	0	342	0.20%	92.80%	7.00%	89
951123	T13	2,033	0	305	0.20%	94.30%	5.50%	258
951122	T10	2,041	365	296	0.10%	93.30%	6.60%	1,037
951125	T16	1,902	251	349	0.20%	43.40%	56.30%	20
951127	T20	1,967	253	318	1.50%	41.10%	57.40%	22
951127	T21	1,964	259	319	0.10%	19.20%	80.80%	17
951125	T17	2,057	261	347	0.20%	63.50%	36.30%	25
951124	T14	1,920	345	348	0.70%	32.10%	67.10%	22
951124	T15	1,925	347	350	0.50%	30.40%	69.10%	22
951119	T05	1,960	353	414	1.40%	75.90%	22.80%	43
951128	T23	1,975	356	330	0.80%	16.00%	83.00%	15
951119	T04	1,994	359	412	0.90%	78.40%	20.70%	60
951121	T08	2,011	361	346	0.70%	50.00%	49.30%	20
951121	T09	2,090	374	353	1.30%	72.30%	26.40%	24
951128	T22	2,204	397	323	0.10%	7.90%	92.00%	17
951122	T11	1,989	416	304	2.20%	24.20%	73.40%	22

When 15 lb/hr (200 mg/dsm^3 @ 7% O_2) of PAC is introduced, not only is the mercury concentration substantially reduced, but the distribution changes from being mostly caught in the back-half acidified peroxide impingers (Hg^{+2}) to being mostly caught in the potassium permanganate impingers (Hg°). Little mercury is caught in the probe and filter making up the front-half of the Method 29 sampling train. These observations indicate that mercury leaving MWCs is mostly $HgCl_2$ or some other ionic form. This is similar to the distribution observed by USEPA at Stanislaus, CA (1993) and Camden, NJ (1993) and by Richman, et al at Marion County (1993). There is no statistically significant difference between the mercury distribution with 15 and 30 lb/hr of PAC indicating that 15 lb/hr (200 mg/dsm^3 @ 7% O_2) should be sufficient to bring the concentration below the 80 µg/dsm^3 @ 7% O_2 emissions guidelines for mercury.

Temperature has a relatively significant effect on the results, but even at 420°F, 200 mg/dsm^3 @7% O_2 of PAC should be able to keep average emissions below the federal emission guidelines. Test compliance may

be achieved when operating below 350°F with as little as 100 mg/dsm^3 @ 7% O_2 of PAC added to the flue gas based on these test results.

3.2.3 Acid Gas Air Emissions Reductions

The results indicate that trona, a natural sodium sesquicarbonate ore, is capable of generally achieving better than 50 percent reductions in HCl and SO_2.[2] The performance of the dry sorbent injection system for HCl and SO_2 removal is summarized in Figures 3-4 and 3-5.

Since only one level of trona was tested, 150 lb/hr or 2,000 mg/dsm^3 @ 7% O_2, the extrapolations shown for lower feed rates are the result of normal concentration variability with changes in flue gas flow rather than being the result of a designed experiment and must, therefore, be viewed cautiously.

Testing by others is summarized in Appendix D which can be used to guide extrapolations. Several of these tests indicate that 96 percent HCl removal can be achieved using DSI at stoichiometric ratios around 1.7:1 which is equivalent to 3,400 mg/dsm^3 @ 7% O_2 or 250 lb/hr at DCERF. Like the limited reports of particulate exceedances at other facilities at unspecified reagent injection rates, DCERF experienced particulate emissions in excess of their 0.024 gr/dsft^3 @ 7% O_2 permit limitation during a 227 lb/hr historic trona injection rate run conducted during a prior process optimization test program. The amount of reagent that can be routinely added is constrained by the particulate control capability of each facility's ESP.

The HCl removal results are highly variable. The reason for the variability is not immediately evident because the facility design and trona injection location did not allow inlet concentrations to be measured. Removal efficiencies were calculated on the basis of average uncontrolled levels and may not represent the full range of inlet values experienced during testing. At 350°F, for example, a wide range of removal efficiencies is shown. Since PAC is unlikely to affect HCl removal, the most likely explanation is that the average uncontrolled HCl concentration does not represent the HCl actually present during these two runs. If the highest historical HCl concentration is used in the efficiency calculation, rather than the average, then the removal efficiency for the two low 350°F runs rises to around 65 percent and is in line with the balance of the results. When the Langmuir thin film adsorption type performance model is fit to the data, five data points are identified as outliers. In addition to the two visibly low performing 350°F runs, the two low performing 420°F runs and the highest 350°F run are also inconsistent with the bulk of the data. These too can be brought in line by substituting either the historically high or low uncontrolled HCl concentration. Such a substitution was not made to avoid bias problems stemming form arbitrary substitutions.

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[2] SO_2 and HCl removal occur after the sodium sesquicarbonate is calcined to produce sodium carbonate via the following reaction:

$$2[Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O] \rightarrow 3\,Na_2CO_3 + 5\,H_2O + CO_2$$

The sodium carbonate (Na_2CO_3) then reacts with SO_2 and HCl as follows:

$$Na_2CO_3 + SO_2 \rightarrow Na_2SO_3 + CO_2$$
$$Na_2CO_3 + SO_2 + \tfrac{1}{2}O_2 \rightarrow Na_2SO_4 + CO_2$$
and $$Na_2CO_3 + 2\,HCl \rightarrow 2NaCl + H_20 + CO_2$$

Processed trona ore is typically 98 percent sodium sesquicarbonate. Stoichiometric quantities of processed trona are 2.4 g per g of SO_2 and 2.1 g per g of HCl.

Hydrogen Chloride -- PPMdv @ 7% O2						
Trona	PAC	STACK TEMPERATURE - °F				average
lb/hr	lb/hr	420	350	320	300	
0	0	542 394				468
150	0	340 341 193 158	148 160		170 177	211
150	15		174 141	169 257		185
150	30	300 252	221 260 399 175	247	139	249
average		315	210	224	162	243

Hydrogen Chloride Removal Efficiency						
Trona	PAC	STACK TEMPERATURE - °F				average
lb/hr	lb/hr	420	350	320	300	
0	0					
150	0	27% 27% 59% 66%	68% 66%		64% 62%	55%
150	15		63% 70%	64% 45%		60%
150	30	36% 46%	53% 44% 15% 63%	47%	70%	47%
average		44%	55%	52%	65%	53%

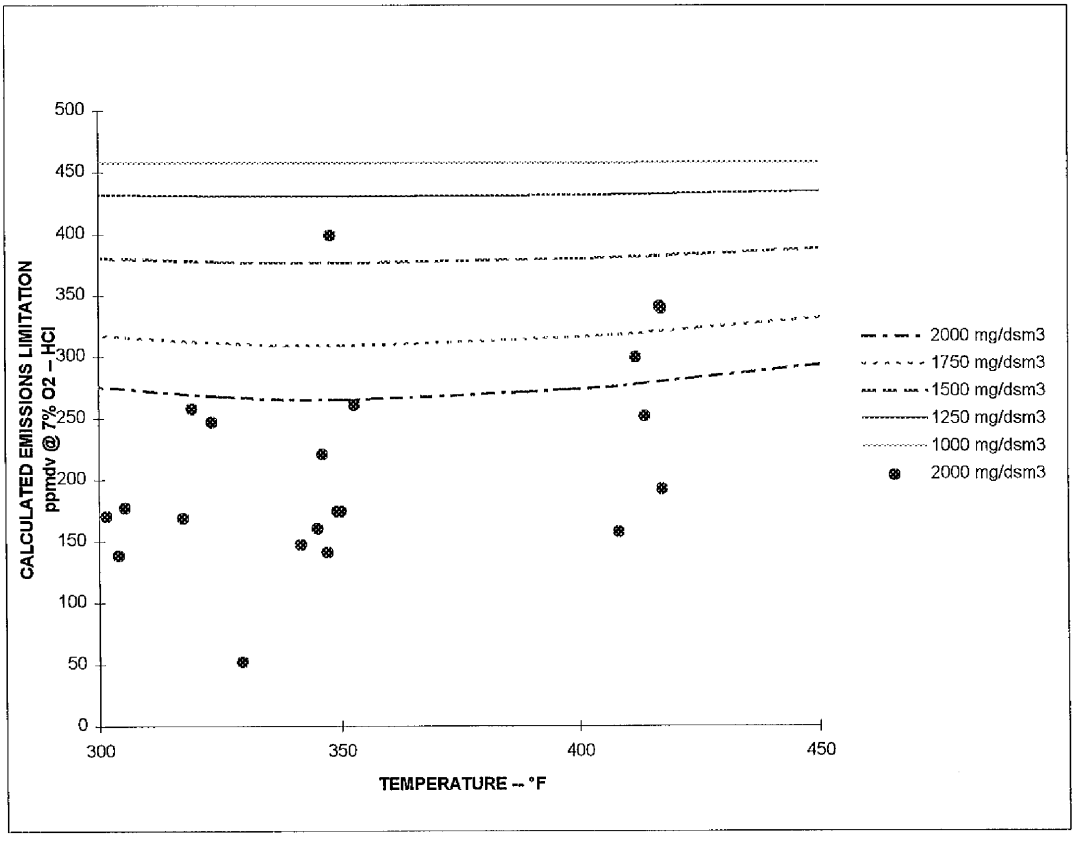


Figure 3-4 Hydrogen chloride emissions test results and calculated emission limitations.

Sulfur Dioxide -- PPMdv @ 7% O2						
Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	131 85				108
150	0	96 41 43	48 34		53 56	53
150	15		53 48	46 25		43
150	30	62 49	41 37 42 51	36 52	34	45
average		72	44	40	48	53

Sulfur Dioxide Removal Efficiency						
Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0					
150	0	11% 62% 60%	56% 69%		51% 48%	51%
150	15		51% 56%	57% 77%		60%
150	30	43% 55%	62% 66% 61% 53%	67% 52%	69%	59%
average		46%	59%	63%	56%	56%

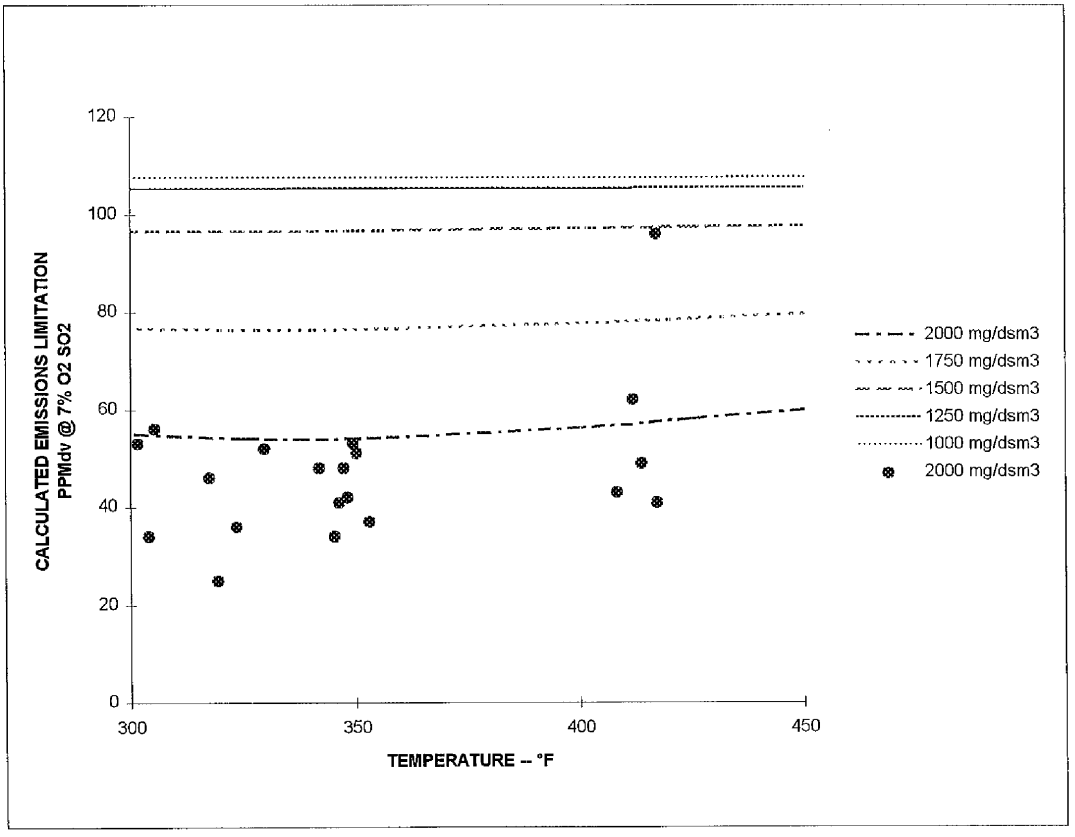


Figure 3-5 Sulfur dioxide emissions test results and calculated emission limitations.

The calculated emissions limitation for HCl is near the small plant guideline on stack concentrations, but is above the required 50 percent removal efficiency. Additional trona is required to provide a comfortable margin for compliance on the basis of outlet concentrations. Alternatively, a facility permit could be written in terms of maintaining the reagent feed rate needed to maintain 50 percent removal under historically high inlet concentrations. This approach may be needed in facilities which cannot effectively monitor inlet concentrations like DCERF. It is similar to the continuous assurance monitoring approach when PAC is used to control mercury and PCDD/Fs.

This demonstration test did not address the question of the benefits of higher trona addition rates. Figure 3-4 includes an emissions limitation extrapolation to 2,500 mg/dsm^3 @ 7% O_2 of trona. This line is not materially different than the one for 2,000 mg/ dsm^3 @ 7% O_2 of trona. While this may be a mathematical anomaly resulting from moving away from the data centroid, it may also reflect the real behavior of the system.

Figure 3-6 contains graphs which show HCl and SO_2 removal efficiencies. From these graphs, it appears likely that HCl and SO_2 removals in excess of 50 percent are achievable. Reaching the 80 and 95 percent levels mandated for large plants in Subpart Cb appears unlikely.

SO_2 emissions were calculated using the procedures in Method 19; that is, the hourly average concentrations were adjusted to 24 hour geometric means before calculating concentrations and removal efficiency. The data standard deviation is small enough that this adjustment did not have a material effect on the result. SO_2 emissions meet small plant performance guidelines for removal efficiency and concentration. Like HCl, PAC addition does not affect SO_2 removal.

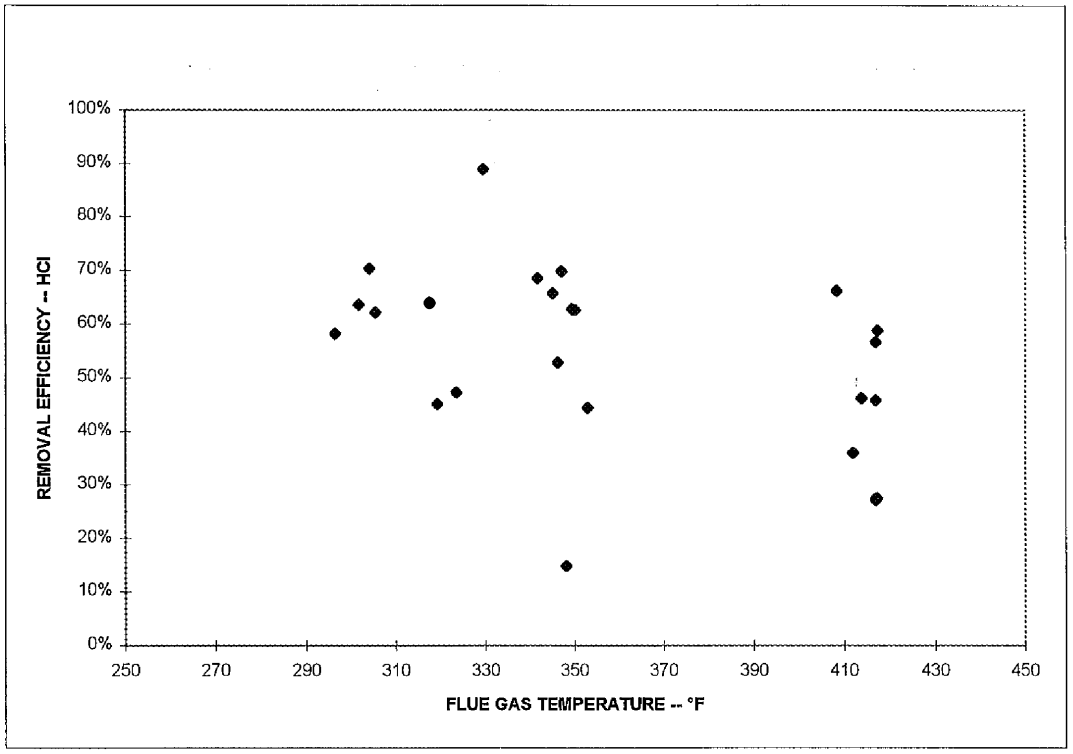
3.2.4 Other Section 129 Pollutant Air Emissions Reductions

Figures 3-7 and 3-8 are emissions summaries for other Section 129 regulated pollutants associated with the products of combustion (NO_x, CO) and the particulates (opacity, cadmium and lead). Results are also provided for total hydrocarbons since they are frequently proffered as a PCDD/F surrogate.

NO_x emissions were adjusted to 24 hour average concentrations following the Method 19 procedure described above. Uncontrolled NO_x at DCERF averaged 140 ppmdv. They were not expected to be materially affected by the dry injection of trona or PAC. Indeed, they were not; thus confirming the expectation.

Carbon monoxide concentrations are the averages observed during each run. They are generally 4 hour averages, although a few 5 hour averages are included. The data indicates that DCERF was operating in compliance with the emissions guidelines during testing. No difference between test conditions was observed.

Total hydrocarbons were measured using a flame ionization detector throughout testing. They are generally low and exhibit no trend with PAC or trona addition or APCS operating temperature. Since these combustion related pollutants are formed in the furnace, they should not be materially affected by the downstream temperature interventions applied during these tests. The lack of a response to PAC is interesting. It appears that whatever organics make up these emissions, they are not adsorbed by PAC. This becomes particularly significant when the other organics frequently proffered as PCDD/F surrogates are considered. For example, the chlorobenzene family has been found in at least one experiment to correlate with PCDD/F concentrations (NYSERDA, 1987). When the data in Appendix A are considered, a strong correlation exists between total chlorobenzenes and total PCDD/F when PAC is not used. Once PAC is added, however, the correlation becomes statistically insignificant. The sign is negative indicating more



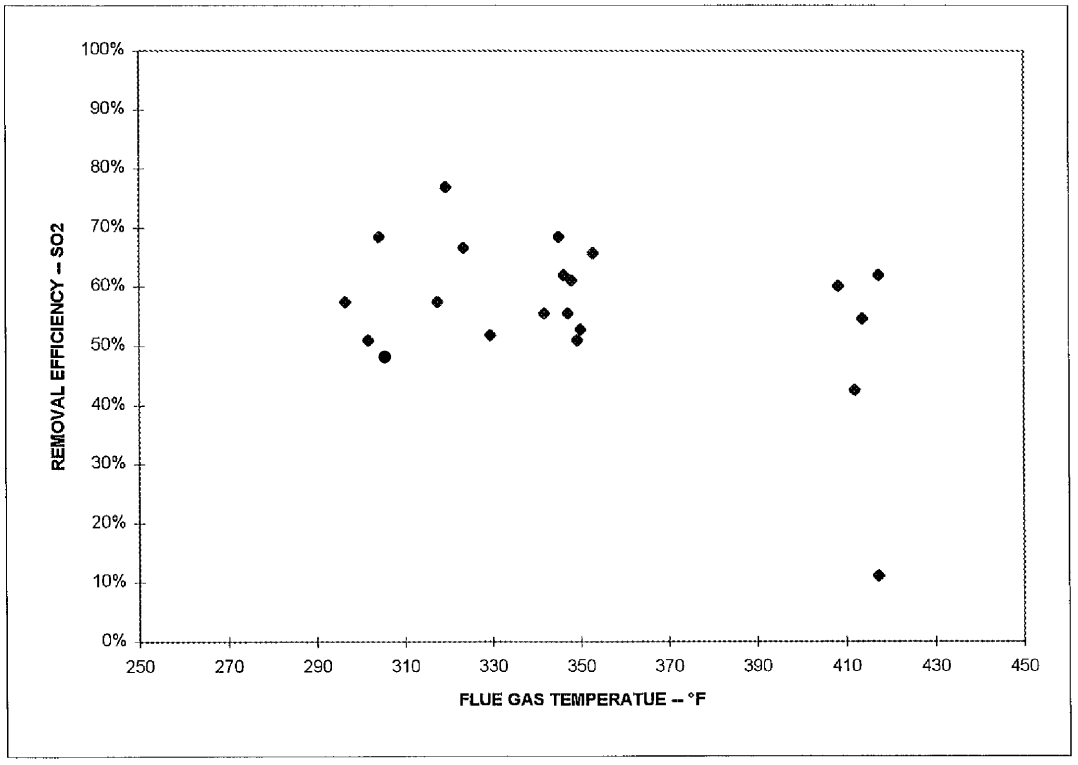


Figure 3-6 HCl and SO2 removal efficiencies

Oxides of Nitrogen -- PPMdv @ 7% O2						
Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	242 236				239
150	0	269 256 227	219 216		260 270	245
150	15		353 251	241 249		274
150	30	227 236	242 223 259 264	233 237	215	237
average		242	253	240	248	247

Total Hydrocarbons -- PPMdv @ 7% o2						
Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	0.67 0.61				0.64
150	0	2.00 1.49 1.16	0.32 2.97		0.54 1.75	1.46
150	15		1.23 1.13	0.42 5.06		1.96
150	30	0.91 1.08	1.03 0.14 0.21 0.77	0.45 0.70	1.17	0.72
average		1.13	0.98	1.66	1.15	1.17

Carbon Monoxide -- PPMdv @ 7% O2						
Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	42 52				47
150	0	56 70 83	60		63 61	66
150	15		84 70	50		68
150	30	62 69	48 70 78 58	62 56	63	63
average		62	67	56	62	63

Figure 3-7 Product of combustion related pollutant concentrations.

Particulates -- mg/dsm3 @ 7% O2

Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	6.7 2.9				4.8
150	0	20.5 9.4 12.4	4.6 4.0		2.5 0.9	7.8
150	15		1.3 5.8	2.0 7.6		4.2
150	30	5.5 6.9	0.2 5.0	30.5 19.7	6.3	4.8
average		9.2	3.5	4.8	3.3	7.7

Note: Underlined values excluded from averages.

OPACITY -- PERCENT

Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	1.7 1.8				1.8
150	0	2.4 2.3 2.4	2.1		2.8 3.1	2.5
150	15		2.3 2.7	2.1		2.4
150	30	2.2 2.2	2.0 2.3 2.0 2.5	1.7 1.9	3.0	2.2
average		2.2	2.3	1.9	2.9	2.3

Cadmium -- ug/dsm3 @ 7% O2

Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	16 9				12
150	0	18 12 14	6 8		7 9	11
150	15		7 133	58 90		72
150	30	16 17	4 6 7 9	262 16	12	39
average		14	23	107	9	34

Lead -- ug/dsm3 @ 7% O2

Trona lb/hr	PAC lb/hr	STACK TEMPERATURE - °F 420	350	320	300	average
0	0	168 82				125
150	0	249 293 485	104 220		115 102	224
150	15		112 183	80 111		121
150	30	163 170	60 141 126 110	146 210	103	137
average		230	132	137	107	160

Figure 3-8 Particulate related emissions test results.

total chlorobenzene equals less PCDD/F—not the reverse as some intimate—a natural consequence of PAC adsorbing PCDD/F, but not chlorobenzenes.

Particulate emissions from the ESP were all well within regulatory limits. Results for the 320°F, 30 lb/hr (400 mg/dsm^3 @ 7% O_2) PAC and 150 lb/hr (2,000 mg/dsm^3 @ 7% O_2) trona test condition are in compliance, but were taken under upset conditions since the first precipitator hopper was found to be plugged at the end of that day's testing. Thus, these test results may overstate actual emissions.

Adding trona had a small effect on ESP performance at the tested injection rate. Compared to the no-trona baseline, 150 lb/hr of trona produced roughly a doubling of particulate emissions. Adding 150 lb/hr of trona is equivalent to adding 2,000 mg/dsm^3 @ 7% O_2—about 1 gr/dsft^3 @ 7% O_2—a flux that is about equal to the ESP inlet particulate concentrations measured at other mass burn MWCs contained in Rigo & Rigo's proprietary emissions database.

Table 3-4 is a summary log of ESP field voltages, currents, and spark rates. When the flue gas temperature was reduced using humidification, the performance of the precipitator improved. With the addition of enough water to reduce the flue gas temperature to 350°F, the average secondary voltage increased about 5 kV and the spark rate fell to very low levels suggesting performance could be further improved for these conditions by increasing the secondary voltage until the spark rate returned to normal.

The improvement in ESP performance with water spray temperature control indicates that this may be sufficient to keep existing precipitators in compliance—or bring them into compliance—even if the inlet loading is increased with acid gas reagent and PAC injection.

Unlike the effect of trona injection, when PAC was added the result was reduced particulate emissions regardless of ESP operating temperature. Emissions returned to no-trona levels with PAC and trona addition. This is a plausible result if the PAC either improves the condition of the particulate cake on the precipitator plates (reentrainment is minimized during collector plate rapping to transfer collected particulate to hoppers for removal from the system) or alters the cake's electrical properties so that the back-corona potential is reduced.

The PAC was ground to pass a 325 mesh screen; the top-size is 44 μm. While this is an intuitively fine material, it is a large aerosol that quickly settles in ESPs. Consequently, it is plausible that PAC addition does not increase emissions because its removal is governed by the settling characteristics of the aerosol and ESP dimensions rather than the aerosol's electrical and drag properties. Such an argument might not apply to trona since it is explosively pulverized by water and CO_2 evolution during calcining to sodium carbonate which regrows to an unknown extent when reacting with HCl and SO_2.

Average opacity was independent of trona and PAC feed rates. This indicates that either emissions are low enough that the transmissometer is measuring at the low end of its sensitivity, or that any changes in emitted aerosol are associated with particulates large enough to not affect the light scattering characteristics of the stack gases.

The particulate associated emissions complied with the emissions guidelines requirements. Cadmium and lead emissions were generally constant for all test conditions, although there are a few high spikes, particularly in cadmium. This may be the result of MSW characteristics, rather than any change in particulate emissions. Cadmium and lead are semi-volatile metals. That is, they volatilize under furnace conditions, but condense on particulate surfaces at ESP operating temperatures. As such, they should be found with the fine particulates associated with the majority of the surface area (not particulate mass). The lack of

Table 3-4 ESP electrical characteristics during testing.

DATE	TIME	SECONDARY kV	SECONDARY mA	SPARK RATE	SECONDARY kV	SECONDARY mA	SPARK RATE	SECONDARY kV	SECONDARY mA	SPARK RATE
951117	709	30		185	26		180	25		68
951118	800	26		174	22		182	24		126
	900	23	90	216	23	500	152	24	420	108
	AVERAGE	25		195	23		167	24		117
951120	706	23	100	230	23	350	230	25	440	175
	1645	25	70	128	24.5	440	196	25.6	400	124
	AVERAGE	24	85	179	24	395	213	25	420	150
951121	659	25	50	20	26	415	56	27	360	0
	1242	25	60	16	25	400	116	27	350	0
	AVERAGE	25	55	18	26	408	86	27	355	0
951122		25	40	0	26	310	16	27	310	0
951121	720	30	60	4	31	410	32	32	350	350
	935	30	55	12	31	395	68	32	340	0
	1239	29	60	52	30	395	56	32	350	4
	1350	29	40	32	30	290	136	32	335	0
	1452	30	35	20	30	230	264	32	310	24
	1558	28	70	268	28	250	244	32	300	120
	1700	30	70	192	30	340	204	32	370	100
	AVERAGE	29	56	83	30	330	143	32	336	85
951122	700	32	40	0	32	320	16	32	310	0
	1004	30	40	0	32	500	12	32	270	0
	1120	30	40	0	32	500	36	32	250	0
	1520	30	65	0	32	460	68	32	285	0
	1704	30	60	0	32	330	20	32	290	0
	AVERAGE	30	49	0	32	422	30	32	281	0
951123	702	30	50	0	32	280	36	32	300	0
	952	30	60	0	32	320	12	32	290	0
	1059	30	50	0	32	280	24	32	270	0
	1414	30	50	0	32	270	8	32	280	0
	1519	30	40	0	32	240	6	32	240	0
	1802	30	40	0	32	270	0	32	270	0
	AVERAGE	30	48	0	32	277	15	32	275	0
951124	726	30	50	24	30	320	132	32	330	8
	818	30	50	12	31	350	56	32	340	8
	1106	30	80	104	30	450	48	33	370	0
	1229	30	30	0	32	250	44	31	310	20
	1445	30	30	0	32	280	20	32	320	4
	1708	29	40	4	32	280	64	31	325	8
	AVERAGE	30	47	24	31	322	61	32	333	8
951125	759	30	40	4	32	340	52	32	330	0
	1154	30	50	0	32	490	0	32	330	0
	1754	30	35	8	31	250	160	32	320	12
	AVERAGE	30	42	4	32	360	71	32	327	4
951126	650	30	60	52	30	340	196	32	330	0
	1100	30	50	44	32	340	88	32	350	4
	1640	32	50	4	30	210	68	32	320	36
	AVERAGE	31	53	33	31	297	117	32	333	13
951127	752	30	50	0	30	300	32	32	290	12
	1420	30	50	0	32	290	8	32	280	0
	1710	30	30	0	32	230	12	32	270	4
	AVERAGE	30	43	0	31	273	17	32	280	5
951128	716	30	35	0	32	290	0	32	280	4

change in total particulate emissions, coupled with improved ESP electrical performance characteristics with the addition of PAC and temperature reduction, indicates that any change is due to these phenomena rather than the designed interventions. If the few high lead and cadmium results are statistical outliers and not representative of average performance, then there is an indication that reduced temperature operation reduces emissions of these metals. While substantially less concentrated than the respective metal chloride saturation points, perhaps surface sorption is enhanced by lower temperatures as would be predicted by simple equilibrium models applied to saturated systems.

3.2.5 Combined Residue Results

Toxic Characteristics Leaching procedure [TCLP] results for the combined ash samples collected during testing are presented in Table 3-5. These samples were collected according to the plant's residue sampling and handling procedure and represent composite samples over the time when trona and PAC were being utilized. While physical plant limitations prevent precise determination of the test conditions represented by each sample, the results are encouraging. Like historical TCLP results for the facility, these exhibit no discernible TCLP organics trends; the results are all BDL and no interpretation is appropriate.

When the TCLP results for this test are combined with the results of other 1994 DCERF testing shown in Table 3-6, the time weighted characteristics are 0.8 mg/L for cadmium and 1.6 mg/L for lead. These are classified RCRA non-hazardous waste. Nevertheless, the metals results indicate a potential problem when using 150 lb/hr of trona. Historically, the facility uses 100 to 125 lb/hr of trona to control acid gases. With this addition rate, extraction fluid No. 1 is indicated, the final extract pH is around 7 and the metals concentrations are less than one third to one-half of the regulatory limits. With 150 lb/hr (2,000 mg/dsm^3 @ 7% O_2) of trona, extraction fluid No. 2 is indicated and the final extract pH is around 5. Consequently, careful attention has to be paid to the amount of excess acid gas sorbent to make sure that necessary HCl and SO_2 emissions reductions are achieved while leaving an appropriate amount to ensure the environmental safety of the resulting residues. Operating this facility below 1,333 mg/dsm^3 @ 7% O_2 or above 2,500 mg/dsm^3 @ 7% O_2 trona injection rate avoids the potential for a problem.

3.3 System Operating Experience

3.3.1 Powdered Activated Carbon [PAC] System

As described in Section 2, PAC was metered from 900-lb bags into the gas stream using a temporary system. In most facilities, this would be accomplished using a pneumatic transport system; however, project constraints suggested an alternative arrangement for testing. The existing pneumatic transfer system for acid gas reagents had the capacity to mix and transfer PAC along with trona to the required injection point. Introducing PAC into the existing system had to be accomplished without upsetting the existing operation. This precluded the use of a pneumatic PAC transport system because the added air would unbalance the trona transport system and de-entrainment devices would be needed. The most effective system would have been to have the PAC exiting the screw feeder fed directly to the eductor drop tube. Unfortunately, space limitations precluded mounting the PAC feeder above the eductor drop tube. Instead, the unit was installed outside the reagent room and PAC was metered onto a sidewalled, pin-belt conveyor which discharged through a transition chute to the open end of the trona eductor feed pipe.

The bagged PAC was supplied in an inner polyethylene bag with a discharge nozzle and an outer woven synthetic fiber bag equipped with lifting straps and a nozzle shroud. Installing each new bag required several steps. After hoisting the bag into position above the hopper of the feeder, the operator opened the bottom of the outer bag and extracted the nozzles which are factory sealed with a Velcro strap closure. The

Table 3-5 TCLP leaching test results.

SAMPLE ID	EXTRACTION FLUID	FINAL LEACHATE pH	SILVER mg/L	ARSENIC mg/L	BARIUM mg/L	CADMIUM mg/L	CHROMIUM mg/L	MERCURY mg/L	LEAD mg/L	SELENIUM mg/L
20 A TCLP	2	5.2	(0.02)	(0.2)	0.5	1.7	0.2	0.0002	26.0	(0.2)
20 P TCLP	2	5.4	(0.02)	(0.2)	0.8	1.6	0.1	0.0005	17.0	(0.2)
22 A TCLP	2	5.0	(0.02)	(0.2)	0.5	1.3	0.1	0.0004	15.0	(0.2)
24 A TCLP	2	4.9	(0.02)	(0.2)	0.6	1.0	0.1	0.0005	25.0	(0.2)
24 P TCLP	2	4.9	(0.02)	(0.2)	0.2	1.3	0.2	0.0003	18.0	(0.2)
27 A TCLP	2	4.9	(0.02)	(0.2)	0.3	1.5	0.1	0.0002	18.0	(0.2)
27 P TCLP	2	4.9	(0.02)	(0.2)	0.4	1.0	0.2	0.0003	17.0	(0.2)
28 A TCLP	2	5.0	(0.02)	(0.2)	0.2	1.5	0.1	0.0004	26.0	(0.2)
28 P TCLP	2	4.9	(0.02)	(0.2)	0.4	1.0	0.2	0.0003	15.0	(0.2)
29 P TCLP	2	4.9	(0.02)	(0.2)	0.2	1.4	0.2	0.0002	17.0	(0.2)

	1,4-dichlorobenzene mg/L	2,4,5-trichlorophenol mg/L	2,4,6-trichlorophenol mg/L	2,4-dinitrotoluene mg/L	2-methylphenol mg/L	3/4-methylphenol mg/L	hexachlorobenzene mg/L	hexachlorobutadiene mg/L	hexachloroethane mg/L	nitrobenzene mg/L
20 A TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
20 P TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
22 A TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
24 A TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
24 P TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
27 A TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
27 P TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
28 A TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
28 P TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
29 P TCLP	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)

	pentachlorophenol mg/L	pyridine mg/L	chlordane µg/L	endrin µg/L	gamma-BHC µg/L	heptachlor µg/L	methoxychlor µg/L	toxaphene µg/L	2,4,5-TP µg/L	2,4-D µg/L
20 A TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)
20 P TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)
22 A TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)
24 A TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)
24 P TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)
27 A TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)
27 P TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)
28 A TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)
28 P TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)
29 P TCLP	(0.5)	(0.1)	(0.1)	(0.1)	(0.02)	(0.02)	(0.5)	(1.0)	(0.5)	(5.0)

	1,1-dichlorethene µg/L	1,2-dichlorethane µg/L	2-butanone µg/L	benzene µg/L	arbon tetrachlori µg/L	chlorobenzene µg/L	chloroform µg/L	tetrachlorethene µg/L	trichloroethene µg/L	vinyl chloride µg/L
20 A TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
20 P TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
22 A TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
24 A TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
24 P TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
27 A TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
27 P TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
28 A TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
28 P TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
29 P TCLP	(0.1)	(0.1)	(0.5)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)

Table 3-6 Current and historic TCLP metals results.

SAMPLE ID	EXTRACTION FLUID	FINAL LEACHATE pH	SILVER mg/L	ARSENIC mg/L	BARIUM mg/L	CADMIUM mg/L	CHROMIUM mg/L	MERCURY mg/L	LEAD mg/L	SELENIUM mg/L
20 A TCLP	2	5.2	(0.02)	(0.2)	0.5	1.7	0.2	0.0002	26.0	(0.2)
20 P TCLP	2	5.4	(0.02)	(0.2)	0.8	1.6	0.1	0.0005	17.0	(0.2)
22 A TCLP	2	5.0	(0.02)	(0.2)	0.5	1.3	0.1	0.0004	15.0	(0.2)
24 A TCLP	2	4.9	(0.02)	(0.2)	0.6	1.0	0.1	0.0005	25.0	(0.2)
24 P TCLP	2	4.9	(0.02)	(0.2)	0.2	1.3	0.2	0.0003	18.0	(0.2)
27 A TCLP	2	4.9	(0.02)	(0.2)	0.3	1.5	0.1	0.0002	18.0	(0.2)
27 P TCLP	2	4.9	(0.02)	(0.2)	0.4	1.0	0.2	0.0003	17.0	(0.2)
28 A TCLP	2	5.0	(0.02)	(0.2)	0.2	1.5	0.1	0.0004	26.0	(0.2)
28 P TCLP	2	4.9	(0.02)	(0.2)	0.4	1.0	0.2	0.0003	15.0	(0.2)
29 P TCLP	2	4.9	(0.02)	(0.2)	0.2	1.4	0.2	0.0002	17.0	(0.2)
25-A-9-2	1	7.4	(0.01)	0.1	0.3	0.2	(0.02)	0.0003	0.7	(0.1)
25-B-9-1	1	7.3				0.1			0.4	
26-A-9-2	1	6.7				0.6			0.4	
26-B-9-1	1	7.6				0.2			0.2	
27-A-9-1	1	7.8				0.1			0.1	
28-B-9-1	1	7.0				0.4			0.3	
29-A-9-1	1	7.0				0.8			0.9	
29-B-9-1	1	7.3				0.2			0.1	
02-A-10-1	1	8.0				0.1			0.2	
02-B-10-2	1	7.6				(0.1)			(0.01)	
03-A-10-2	1	7.3				0.8			0.6	
03-B-10-1	1	7.1				0.7			0.4	
04-A-10-1	1	7.2				(0.1)			(0.01)	
04-B-10-2	1	6.5	(0.01)	0.1	0.3	1.2	(0.02)	0.0012	2.3	(0.1)

inner bag snout was then untwisted and spread open over the fluidizing nozzle located in the center of the feeder hopper. The snout was spread as wide as possible to facilitate PAC flow. The outer bag was then clamped around the feed hopper. After banding the outer bag, the Velcro closure was removed and the fluidizing nozzle operated manually to start PAC flow.

Routine inspections during the initial testing periods showed the PAC to be flowing each time the inspection was completed. However, operating statistics (Table 3-7) suggest that the system did not really work continuously as indicated by the screw speed indicator. The total operating time for each bag exceeded that which would have been expected.

Table 3-7 Operations log for powdered activated carbon system.

Bag No	Start Date	Start Time	Stop Date	Stop Time	Elapsed Time (hr)	Feed Rate (lb/hr)	Total Fed (lb)
1	18-Nov-95	2030	19-Nov-95	2000	23.5	30	705
	20-Nov-95	2130	21-Nov-95	1700	19.5	30	585
Sub-Totals					43		1290
2	21-Nov-95	1730	22-Nov-95	1830	23	30	690[1]
	23-Nov-95	1900	24-Nov-95	1820	23.3	30	699
	24-Nov-95	1820	25-Nov-95	830	12	15	180
Sub-Totals					58.3		1569
3	25-Nov-95	915	25-Nov-95	1915	10	15	150
	26-Nov-95	1730	28-Nov-95	730	38	15	570[2]
	28-Nov-95	730	29-Nov-95	100	17.5	30	525[3]
Sub-Totals					65.5		1245

[1]Trona system plugged 0650 on 22; operators notes indicated problem during night feed off 2 hr; PAC feeding problem @ 1330 on 22; 1530 red level light on; N2 cylinder changed 1630
[2]27@ 0754 reagent room filled with carbon; fluidized too much?
[3]Feeder and conveyor jammed with PAC on morning 29.

While off-line time is accounted for in the table, the actual out-of-service time may have varied from that recorded. On several occasions, the hopper alarm on the PAC feeder triggered and reset automatically. These level alarms indicate the absence of PAC in the hopper. The fact that the alarms would automatically reset suggests that flow from the bag could be interrupted and self-restored. How often this occurred during hours when test personnel were off-site is unknown, but on several occasions during testing, system inspection suggested that a "rat-hole" was forming in the bag when material bridged across the opening. This was most evident the morning of November 22, 1995. The field team identified the feed rate for that period as suspect. During the remainder of the test periods, PAC feed appeared to be as planned.

Two other problems were experienced:

- an over-fluidization of the carbon contributed to overfeeding on the morning of November 27, 1995; and

- plugging of the transition chute occurred overnight on November 28-29, 1995 leading to a pin-belt conveyor jam and cessation of operations.

Several lessons should be kept in mind when designing and using a PAC feed system:

- Due to the nature of this material, fluidizing should be done with care.

- All parts of the system should be enclosed to prevent leakage. PAC is extremely fine and migrates easily and everywhere when released.

- Systems should include positive feed rate monitoring. It is insufficient to set a feeder rate control and then leave the system to operate on its own. If bag feeding systems are used, it is imperative that load cells are installed between the frame and the bag and programmed to monitor system performance. On larger systems, loss of weight feeders might be a worthwhile expenditure to provide continuous feed rate data.

- Alarms are needed to identify failures in various parts of the transfer system. These might include pressure sensors in transfer lines to indicate both potential blockage and breaks in the transfer lines.

While the portable PAC dosing system appeared to operate quite well, serious consideration should be given to permanent storage silos to eliminate the manpower requirements for changing bags on a frequent basis and to permit a more thoroughly enclosed system.

3.3.2 Water Spray Cooling System

The water cooling system described in Section 2 includes the spray lance equipped with three Bete Model SA-308 and SA-310 bi-fluid nozzles and air and water supply systems feeding the lance. The fabrication of the lance was accomplished by plant maintenance staff. Insertion of the lance into the duct was relatively straightforward although it took considerable manual effort because the location did not lend itself to use of a hoist.

Both 85 psi air and water were supplied to the lance. The volume of air required, 150 scfm, was too large for the plant air system. An additional compressor was rented and connected to the spray lance using two types of flexible hose and three different clamp arrangements before a successful connection was made. The final installation used 3-inch spiral wrapped Barracuda hose (air) with bolted clamps to attach the quick-disconnect (fire hose) fittings.

Water was supplied from the pumps that had been used for previous water spray cooling development at the facility. Fiberglass reinforced rubber hose was used to connect the pump discharge to the lance. The water supply system included an air-operated plug valve to control water flow and manual shut-off valves around the pumps. The only major system limitation was the control characteristics of the modulating valve. Until the water pressure equalized that of the air, water did not flow. This limited the effective range of the plug valve since it needed to be about 50 percent open before water flow would start. At operating conditions requiring minimal water addition, the limitations in the operating range led to increased control sensitivity. Incremental changes of 1 and 2 percent needed to maintain desired ESP temperature conditions required frequent operator intervention.

Start-up procedures minimized the potential for steam formation in the lance. The lance was inserted into the duct and the air flow was established. Before the initial water connection was made, the water lines

were purged. The water line was then connected to the lance and the water flow initiated. A setting of 55 percent on the valve initially provided 3.3 gpm flow to the lance. The flow was adjusted to 4.3 gpm to drop the ESP operating temperature to 350°F. The initial start-up occurred at 1600 hours on November 20 and operations were uneventful overnight and through the next day. Water flow was increased late in the day on November 21 and outlet temperatures as low as 290°F were recorded the next day with flows of 9.4 gpm.

Prior to testing on November 22, 1995, the system was inspected. The lance was pulled from the duct and the nozzles were replaced with new atomizers although no fouling was evident. During the inspection of the interior of the duct, a soft buildup of trona was noted on top of the economizer. The initial consensus was that this could have been the result of water impingement on the surface via recirculation and subsequent coating with the reagent; however, the significance of the operating staff changing the trona injection point during the night was overlooked. Because of the concern about potential buildup, it was decided that the orientation of the lance should be adjusted to make the spray direction more in the direction of the flow (from 10° above the centerline to 35° below the centerline). To accomplish this, the flange on which the lance was mounted was rotated one hole counterclockwise when it was re-installed. In all, the probe was out of the stack for less than 20 minutes, and temperatures were re-established in the test range by 0910 hours when testing started.

Inspection of the nozzles removed from the lance showed a white deposit on the interior Bete scroll and on the outer wall of the mixing chamber. The holes in the nozzle were clear. The deposits may have been flash deposits created when flow was initiated. Throughout the course of the subsequent testing the water flow rate required to maintain outlet gas temperature increased suggesting potential decreases in the heat transfer performance of the economizer. Inspection prior to power washing on November 29, 1995 showed deposits on various surfaces of the economizer, lending credence to this theory.

Inspection of the lance after eight days of operation showed that while the nozzles were still functional, the realignment had caused increased deposition on the washers and surrounding surfaces. Given that some of the observations of duct deposits suggested that surface impingement may have led to build-ups, the orientation of the lance was returned to the design configuration. An outage occurred on December 4, 1995 that was attributed to deposits sloughing back from the duct to the economizer and quenching was ceased.

Theoretical calculations indicate that gas velocities are reduced to 90 percent of design when the sprays are used. The sprays could also cause some particle agglomeration. Since larger agglomerated particles would settle faster and lower bulk gas velocities also reduce the particle size carried over between the economizer and ESP, even without wall wetting induced by misorienting the nozzles, an accumulation like that depicted in Figure 3-9 could have occurred. Vibrations could set the settled mass in motion and cause it to slough onto the economizer. In configurations like the DCERF, it is important to:

- locate the nozzles far enough in from the ends to prevent wall wetting;
- orient the nozzles slightly above the flow centerline—10° was used here; and
- install a hopper in the underside of the breaching to prevent sloughed sedimented particulates from plugging the economizer.

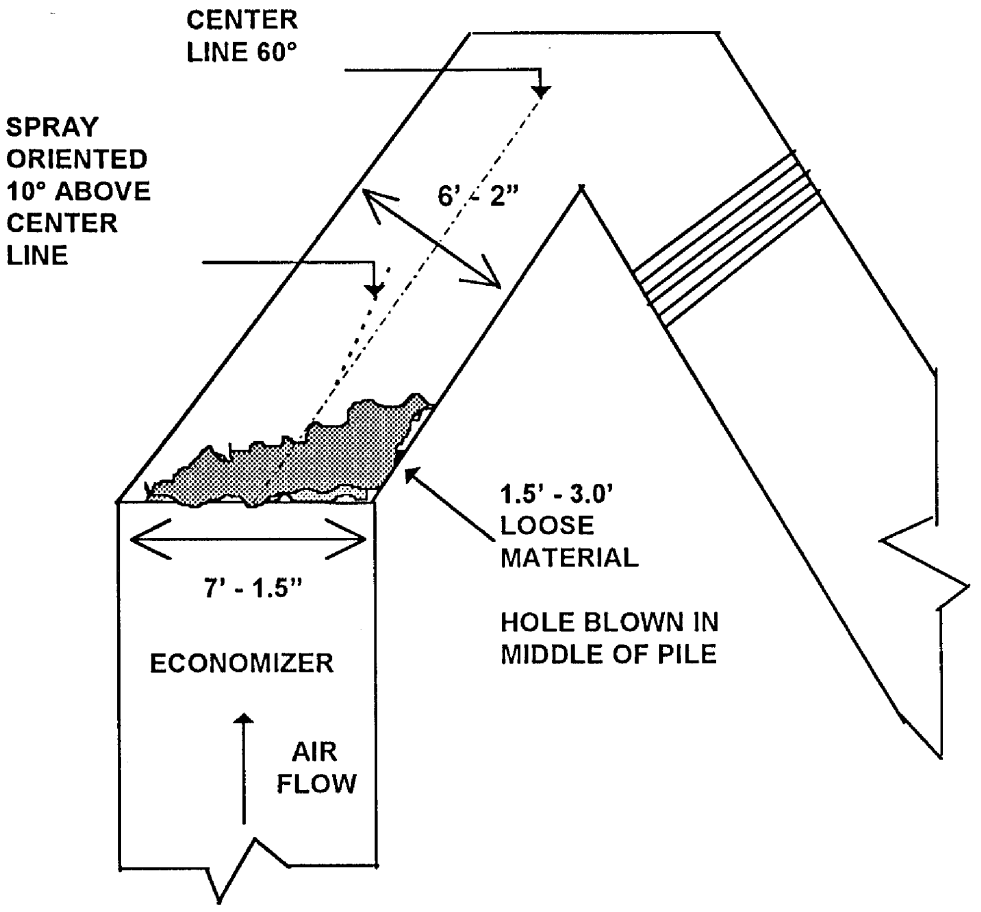


Figure 3-9 Particulate accumulation in the breaching downstream of the economizer.

3.3.3 Dry Sorbent Injection System

DCERF's pollution control system incorporates dry sorbent injection [DSI]. Over the course of 8 years of operation a number of lessons have been learned and modifications made. The system was initially designed to inject dry powdered limestone into the furnace throat through sidewall nozzles. The system proved ineffective because calcination temperatures could not be routinely achieved. When powdered hydrated lime was used instead , the temperatures were high enough to burn the lime and reduce its efficiency. Also, sidewall injection compromised system reliability. When injected that way the jet impinged on the far wall, eroded the refractory and eventually thinned the steel casing.

Trona has been injected both above and below the economizer. Above the economizer, the flue gas temperature is around 420°F and the trona dehydrates and calcines slowly to sodium carbonate before it reacts with HCl. When injected below the economizer, the dehydration and calcination reactions are rapid. To date, no erosion problems have been experienced; however, under low load conditions, trona can accumu-

late in the breaching connecting the economizer outlet and ESP inlet. When the duct is vibrated, the trona slides back on top of the serpentine economizer bank. The sedimented material is loose and frequently passes through the tube bank. Unfortunately, if water sprays are used for gas attemporation, this material would be wetted and could form a solid plug in the economizer.

The dry injection system was made much more effective when the method of injection was changed from wall jet to rapid dust distribution lance. When a wall jet is used, the reagent pattern looks like an expanding herald's trumpet until it impinges against the far wall and splashes back. Even with opposing jets, it was virtually impossible to obtain thorough duct coverage since a portion of the gas stream near the wall is effectively bypassed. The rapid dispersion dry reagent injection lance developed by DCERF resolves this problem by spraying the jet uniformly across the breaching. Visual inspection indicates that full duct coverage is obtained in a matter of 3 to 5 feet. CEMS traverses do not find evidence of stratification.

New lances were fabricated for this test. DCERF has been using similar lances for more than 2 years and they find that replacements are needed about every year to compensate for baffle plate wear. Since these lances are fabricated out of ordinary carbon steel pipe and 1/2 x 3/16 bar stock, they can be fabricated for a few hundred dollars in the plant's shop.

The dry sorbent injection system itself requires maintenance. Elbow, gear and rotor blade wear are common problems. During testing, no unusual occurrences were reported except for the period when the trona injection point was altered from the below economizer point to a secondary location downstream of the spray nozzles. At this point, the sprays impinged on the injection lance, wetted the reagent and formed a hard deposit.

3.4 Quality Assurance Findings

Isokenetics were satisfactory; that is, the sampled gas velocity in the nozzle was within 10 percent of the bulk gas velocity. No bias due to under or over representation of a given size particle is expected. Field procedures described in the Test Protocol in Volume III of this report were followed. Laboratory QA/QC results were within regulatory requirements. One glass rather than quartz filter was used in a Method 29 run. Because a glass filter blank was available, the affected metals could be blank corrected as identified in Table 3-1 by subtracting the full blank value from the measured result. While at variance from Method 29 strictness, the blank was comparatively so high that any other correction made no sense. The laboratory reports in Volume II indicate that no other analytic problems or matrix interferences were encountered.

SECTION 4—CONCLUSIONS & RECOMMENDATIONS

4.1 Demonstrated Emissions Control Characteristics

Table 4-1 is a summary of the results of this effort. Dry sorbent injection with PAC addition is capable of meeting the small plant emissions guidelines; dry sorbent injection alone is incapable of meeting all the large plant emission guidelines for acid gases. An additional interesting finding is that PAC addition alone can bring PCDD/F and mercury emissions into line with the emissions guidelines without temperature control or acid gas reagent addition.

Table 4-1 Results summary.

POLLUTANT	LARGE PLANT GUIDELINES	SMALL PLANT GUIDELINES
Particulates	yes	yes
Lead	yes	yes
Cadmium	probably	yes
Mercury	yes	yes
PCDD/F (Dioxins)	yes	yes
Sulfur Dioxide		
concentration	no	yes
efficiency	if lucky	yes
Hydrogen Chloride		
concentration	no	yes
efficiency	no	yes

4.2 System Operating Characteristics—Lessons Learned

Spray cooling must be carefully done. Dropping the temperature reduces gas velocity and causes particle agglomeration. As a result, sedimentation is increased in the breaching connecting the economizer and electrostatic precipitator. At least a hopper is indicated to intercept sloughing and prevent economizer plugging if settled particulate can slide back onto an incinerator component.

Also, by reducing the flue gas temperature and increasing its moisture, the ESP becomes more susceptible to plugging. The first hopper plugged during testing. This hopper is closest to the screw auger conveyor discharge. Since it was uncovered for about 4 feet and ran only 1/3 full, it is probable that cold air was induced up the auger and into the hopper where it caused condensation and started pozzolonic reactions in the hopper residue. Careful attention to details such as hopper heaters, isolation valves and leakage prevention is indicated.

The PAC system worked satisfactorily for a test rig. Permanent installations should probably include loss-of-weight feeders and pneumatic line flow monitors to detect feed interruptions and blockages before an extensive clean-up is needed.

The trona system worked without problems. A well designed dry acid gas handling system—patterned after years of cement, lime and flour industry experience—should prove satisfactory. The rapid dispersion dust lance has proven effective.

4.3 Recommendation Regarding the Need for Phases II and III

Since this effort was proposed, the final emissions guidelines have been promulgated. As a result, emissions controls are required for mercury and dioxins as well as for particulates and their associated metals, SO_2, HCl and NO_x. Since PAC is currently the only known way of managing mercury and has also demonstrated PCDD/F removal capability, demonstration of dioxin inhibition technology (Phase II) is academically interesting. Given compliance times, such a demonstration is unlikely to affect modification decisions for existing ESP equipped MWCs. It could prove important for new installations.

Phase III, however, is intended to demonstrate sensible flue gas cooling, rather than latent heat of evaporative cooling using water sprays. Additional sensible heat recovery can add to the energy efficiency of an existing MWC and is recommended since this effort demonstrates that reduced ESP operating temperatures improve both emissions and operating economics by minimizing the amount of reagent required.

4.4 Suggestions Regarding Further Research

In order to reliably extrapolate from these results to other operating conditions, additional tests run at different trona injection rates (say 3,000 and 4,000 mg/dsm^3 @ 7% O_2) and lower PAC addition rates (say 67 and 133 mg/dsm^3 @ 7% O_2) are indicated.

The PCDD/F signature analysis provides an indication that 2,3,7,8 substituted congeners are preferentially removed. A physical chemist should be involved to determine if a tailored (synthetic) molecular sieve can be developed to selectively remove these materials.

4.5 Suggestions Regarding Test Procedures

While Method 29 appears satisfactory for Section 129 metals, proof rinses and blank trains (instead of reagent blanks) are indicated to verify recovery and establish method precision. With ever more restrictive emissions limitations, this becomes critical. Poor recovery can set unrealistically low regulatory limits. Limits set within method precision (less than the level of quantification) can only be achieved by chance. The source of the consistently low chromium recovery (a recovery procedure vs. container contamination problem) needs to be established.

Since the confirmatory analysis indicates that 2,3,7,8 TCDFs are over-reported using the standard (DBS) column, total dioxins and ITEQs should be based on the confirmatory (SP2331) column results. Mixture toxic equivalents are overstated 30 to 170 percent when the standard column results for this test are used.

SECTION 5—DATA REDUCTION METHODS & STATISTICAL PROCEDURES

5.1 Data Reduction and Standardization Procedures

Facility performance and emissions were characterized during this test program. The data were all acquired and reduced to engineering units following standard regulatory and engineering procedures.

For manual reference method measurements, the data reduction procedures are described in 40 CFR 60. The methods involve dividing the quantity of pollutant captured by the sampling train (e.g., mg) reported by the analytic laboratory by the reference temperature and pressure corrected dry sampled volume (e.g., dsm^3). This produces emission concentrations in mass per unit volume (e.g., mg/dsm^3). Conversion factors are used to express the result in other mass units (e.g., multiply by 1,000 to get $\mu g/dsm^3$ or divide by 2,289 to get $gr/dsft^3$). If a volumetric concentration is required, ppm_{dv} is estimated using the following equation:

$$ppm_{dv} = 24.042\ (mg/dsm^3)/MW \qquad [1]$$

where:

ppm_{dv} is the concentration in parts per million (volume basis)

mg/dsm^3 is the concentration in mg per cubic meter

MW is the molecular weight of the compound

Pollutant concentrations are finally corrected to USEPA regulatory reference conditions (dry, 101.3 kilopascals [14.7 psi or 760 mm_{Hg}], 20°C [68°F] and 7% O_2) and expressed in appropriate regulatory units (ppm_{dv}, $\mu g/dsm^3$ and ng/dsm^3).

Particular attention was paid to the barometric pressure correction since the facility is located about 5,000 feet above sea level. Unlike coastal sites where the barometric pressure is around 29.8 in_{Hg}, most of the testing was conducted when the atmospheric pressure was 26 in_{Hg}. Consequently, the standardized sample volume is roughly 85 percent of that calculated without the correction.

CEMS monitored pollution concentrations (NO_x, SO_2, CO and THC) were all initially expressed in ppm_{dv}. The CEMS values were all zero and span corrected using the morning, mid-day and evening cylinder gas calibration results. Zero base line and high level span drifts were assumed to occur linearly throughout the period between calibrations.

CEMS data were acquired throughout nominal 4-hour test periods. Regulatory limits, however, are for 24-hour periods. The 10-second CEMS data were accumulated into 15-minute and then the 15-minute averages into 1-hr averages per 40 CFR 60 requirements.

The 1-hour data for each test were introduced into the following equations from Method 19 to develop estimates of 24-hour average controlled and uncontrolled concentrations and removal efficiency:

$$\chi_{ao}^* = \chi_{ao} + t_{(n-1,0.95)}\ (1/n - 1/H)^{1/2}\ S \qquad [2]$$

$$\chi_{ai}^* = \chi_{ai} - t_{(n-1,0.95)}\ (1/n - 1/H)^{1/2}\ S \qquad [3]$$

$$\eta = 1 - \chi_{ao}^{*}/\chi_{ai}^{*} \quad [4]$$

where:

χ_{ao}^{*} is the time period adjusted average outlet concentration

χ_{ai}^{*} is the time period adjusted average inlet concentration

η is removal efficiency

χ_{ao} is the outlet concentration data average

χ_{ai} is the inlet concentration data average

$t_{(n-1,0.95)}$ is the 95 percent statistical confidence level studentized t statistic

n is the number of hours with data

H is the number of hours in the averaging period (24 for SO_2 and NO_x)

S is the data standard deviation

The above equations use concentrations in engineering units to develop arithmetic averages. When the natural logarithms of the concentrations are used in equations 1 and 2, the exponential of the result is the geometric mean. NO_x emissions were characterized using concentrations directly. SO_2 was characterized using the natural logarithms of the concentration data since the regulatory standard is the 24-hour geometric mean.

Removal efficiencies for other pollutants were also calculated using the above formulas. Since the sampling time is the same as the regulatory time for manual method results, n and H are equal; the averaging time adjusted and measured results are the same. That is, no sampling time correction is required.

5.2 Outlier Identification & Management

Any data set is likely to contain recording errors as well as correctly measured and recorded extreme values. Standard statistical parameters, like the arithmetic average and standard deviation, can be greatly distorted by even one incorrectly recorded point.

The entries were reviewed before and after adjustment to standard conditions. If unusual values or patterns were observed, the entries were cross-checked with the original reports for entry errors. If the data were correctly entered, the data reduction was checked.

Errors can occur anywhere in the data reduction, management and interpretation chain from the actual testing through entering the data into the database and normalizing the data. Contaminated testing equipment and poor location of probes can affect the amount of pollutant collected and recovered during tests. Another problem is transcription errors between lab sheets and report summary tables. Data reduction and calculation errors also occur. For example, incorrect molecular weights are sometimes used in calculations; units (i.e., ng vs. pg) can be confused or sample volumes in cubic feet can be substituted when cubic meters are intended. These situations must be addressed before the data are used.

The remaining unusual values are classified as statistical outliers, extreme valued data points. Outliers may be due to:

- errors in the data collection and reporting (sampling, recovery, concentrations, analytic chemistry, recording or calculations);
- undetected but different operating conditions; or
- valid extreme values that arise due to chance alone.

The median is an estimate of the data centroid and 1.483 times the Median Absolute Difference (median of each response minus the median response), or MAD, is a dispersion estimate equal to the standard deviation. Unlike the average and standard deviation, median and MAD withstand up to 50 percent contaminated data so they are very useful for estimating the number of standard deviations a data point is located away from the center of the data. This is a powerful way to identify outliers. As a short-cut, 3/4*IQR[1] can be used as a standard deviation estimate to compute extreme value distances and help identify outliers.

Only duplicate manual method runs were available for most test conditions. Consequently, a near neighbors approach to identifying aberrant data could not be employed since there is no way to know from proximity which point is correct. Rather, the theoretical performance models described later were fit to the data using least median squares regression and data points displaying excessive deviation from the central trend were flagged as statistical outliers.

It is important not to casually discard statistical outliers; they may not be incorrect or truly aberrant. Sometimes the most interesting theories and information are found in the outliers The above method can identify that a point is different, but there may be a cause. For example, low mercury during PAC injection is a response, <u>not</u> a statistical aberration! Outlier identification helps locate data points to check. It does not flag a datum for indiscriminate elimination from the analysis.

Once an outlier was identified, all related data transcriptions and calculations were checked. If the problem remained, field and laboratory reports were scrutinized for previously overlooked problems. Finally, facility performance and operating conditions were reviewed to make sure that the intended operating conditions were achieved so that the data represents what it is supposed to.

A few outliers were found. For example, 30 lb/hr of PAC was scheduled to be injected during run 15. Field observations and cross-checking with the length of time the 900-lb. carbon sack lasted indicates that less PAC than intended was actually fed. The PAC feed rate cross-check is consistent with the system becoming plugged. Zero PAC feed during run 15 is plausible since run 16, the duplicate, is in line with the balance of the data where PAC system plugging was not expected.

Outliers are also caused by the heterogeneous nature of MSW. Baseline tests were conducted without PAC and trona. It is not clear, however, that the baseline results necessarily provide representative uncontrolled conditions for each individual run. Historical plant data were used to establish the range of likely uncontrolled conditions and reasonably expected low and high results attributable to feed variations. In fact, when unusually low or high removal efficiencies are recalculated using extreme historical values, the efficiencies fall in line with the balance of the data. Rather than confound the results of this effort, however,

[1] The Interquartile Range [IQR] is the distance between the lowest and highest 25% of the data. The middle half of the data resides within the IQR.

once changes in MSW characteristics were determined to be the most plausible explanation, that particular outlying result was eliminated from the interpretation.

5.3 Below Detection Limits Data

The project protocol anticipated the potential of below detection limit [BDL] values and developed procedures for handling them. The number of BDL results to be handled was significantly reduced by requiring the laboratory to report tentative (ASTM "T") values when there was an instrument response below the laboratory's Level of Quantitation [LOQ]. The detection limit (labeled "W") is only reported when there was no instrument response at all using an analog output. In the case of digitized outputs, W was assigned if the response was less than 2 percent above the blank correction. Between a 2 percent response and the laboratory's normal quantitation limit, the 3-replicate variance was provided along with the semi-quantitative result.

After minimizing the number of reported BDL results, those values remaining were assigned half the DL as an upper bound when performing statistical analyses and computations that involve the aggregation of results like estimating the total amount of an element in the combined solid waste stream. If all responses for a particular parameter were BDL, the parameter was eliminated from statistical analysis because the results contain no useful data to distinguish between test conditions.

Fortunately, BDL results were not encountered in the regulatory pollutants analyzed in this effort. Non-regulatory pollutant data provided in Appendix A contain BDL results. We suggest that the detection limit [DL][2] be used for pollutants generally found above the LOQ[3] and half the DL (DL/2) be used for all other results when analyzing this data.

Two of the runs exhibited negative particulate emissions. This is most likely a result of the field team's practice of putting any filter crumb remaining on the filter holder in with the impinger catch. The result of this action is that a negative filter weight gain would be observed invalidating the particulate result, but any captured metal would be picked up in the analytic laboratory analysis of the field samples. The associated metals runs would be correct. Field notes and laboratory observations indicated that the filters in question were torn, so these two particulate emissions test results (runs 8 and 9) were discarded; less than zero particulate emissions are an impossible result.

5.4 Determining the Significance of Changes in Emissions Between Test Conditions

Regression based analysis of variance [ANOVA] techniques and robust analysis of theoretical performance models were used to determine if there were changes in emission characteristics as a result of the designed differences in trona and PAC feed rates or APCS operating temperature.

ANOVAs used dummy variables to account for designed feed rate differences. Since there were two levels of trona used, a single binary variable indicating 0 or 150 lb/hr injection rate was sufficient. To characterize PAC addition, however, two binary variables were needed to distinguish no PAC feed (0,0), 15 lb/hr (0,1) and 30 lb/hr (1,0) conditions. Temperature was either treated as a continuous variable or as a set of three binary variables to represent normal operations at 420°F (0,0,0), 350°F (1,0,0), 325°F (0,1,0) and 300°F (0,0,1). In each case, a significant response is indicated if any of the regression coefficients are different than zero at the 95 percent statistical confidence level when a response variable (say, particulate

[2] DL is defined as three times the standard deviation of instrument response when blanks are injected into the instrument.
[3] LOQ is defined as 3.33 times the DL or ten times the standard deviation of instrument response when blanks are injected into the instrument.

emissions) is regressed against the set of binary variables. Due to the small number of runs, interactions could not be considered.

Another way to analyze the data for significant response is to fit the data to a theoretical performance model and look for statistically significant coefficients. Previous analyses have found that models based on Langmuir thin-film adsorption adequately describe the data even though they are not strictly correct since only a quasi-equilibrium (steady state conditions) is reached (Rigo, 1993). The basic form of the Langmuir equations is:

$$\eta = 1/(1+K\chi_i) \qquad [5]$$

where:

η is removal efficiency (dimensionless)

K is the adsorption coefficient (concentration^{-1}), and

χ_i is the uncontrolled pollutant concentration entering the adsorber (ppm or $\mu g/dsm^3$)

Equation 1 can be rearranged and napier logarithms taken to produce an equation that is linear in inlet concentration:

$$\ln(1/\eta-1) = \ln(K) + \ln(\chi_i) \qquad [6]$$

Previous work has shown that K is proportional to the amount of adsorbent present and inversely proportional to the exponential of the absolute APCS temperature. So,

$$\ln(1/\eta-1) = \ln(PAC+1) + T_{inv} + \ln(\chi_i) \qquad [7]$$

where:

PAC is the powdered activated carbon concentration in mg/dsm^3 @ 7% O_2; 1 is added so that when there is no PAC addition, the natural logarithm of the term becomes zero to avoid mathematical difficulties and ease of interpretation, and

T_{inv} is the inverse absolute temperature (1800/R or 1000/K) normalized for convenience.

This equation is of the form:

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + \text{error} \qquad [8]$$

where:

$Y = \ln(1/\eta-1)$

$X_1 = \ln(PAC+1)$

$X_2 = T_{inv}$

$X_3 = \ln(\chi_i)$, and

a_0, a_1, a_2 and a_3 are the regression coefficients.

When equation 7 is fit to the data using robust regression (least median squares), aberrant points are identified as those that exhibit excessive offset from the median line faired through the bulk of the data. These points reside more than 2 standard deviations from the curve built using the median regression coefficients. These coefficients are developed by exhaustively fitting subsets of the data with just enough points (4 in this case) to calculate the value of each coefficient (Rousseeuw and Leroy, 1987).

After outlying points are identified and removed (assigned a weight of zero), standard least squares regression techniques are used to estimate the coefficients based on the main data body. Statistical summary characteristics are also developed for use in estimating emissions limitations.

5.5 Demonstrating Similarity Between Data Sets

Some pollutants like PCDD/F occur as a coherent set of characteristics rather than an individual measure for each run. In order to identify differences and similarities, a method that simultaneously looks at all the isomers and homologue concentrations (i.e., the PCDD/F signature) must be employed. One technique (Rigo, et al., 1995) is cluster analysis, a pattern recognition technique that finds groups of similar results. By looking at the parameters that characterize these groups (PAC addition rate, for example) potentially causative underlying phenomena can be identified.

PCDD/F signatures were calculated to provide a uniform absolute concentration normalized description of this complex organic mixture. Three signature elements were employed:

- the Percent Congener defined as the ratio of 2,3,7,8 Substituted Congeners grouped by equal ITEF within a homologue to the sum of all 2,3,7,8 Substituted Congeners;
- the Percent Homologue defined as the ratio of each homologue total to the Total PCDD/F; and
- the 2,3,7,8 Ratio defined as the sum of all 2,3,7,8 Substituted Congeners to the total PCDD/F.

Each of the above are calculated on a molar rather than on a mass basis to avoid camouflaging changes induced by substituting a few molecules of heavier congeners for more molecules of lighter, more toxic congeners.

Cluster Analysis simultaneously compares the large number of characteristics embedded in the signature, not just a single response.

There are many specific implementations of Cluster Analysis. Alternative measures of group closeness include the Squared Euclidian Distances (sum of the squared differences between each element in two groups), Euclidian Distance (square root of the Squared Euclidian Distance); the city-block distance (sum of the absolute values of the differences); the Chebychev distance metric (the largest difference between groups); an absolute Power metric (the l/r root of the sum of the absolute values of the differences raised to the p power); and the cosine of the vectors of the variables which is a pattern similarity measure:

$(\delta_i x_i y_i / '\{\delta x_i^2 \cdot \delta y_i^2\})$

Clustering begins by calculating the Squared Euclidian Distance between each of the original signature pairs. The two runs that have the smallest coefficient are grouped. The procedure sequentially finds the next closest pair and continues grouping additional pairs of individual signatures or adding another run to the center of a previous group until a single, overall cluster is finally reached.

The result is a dendrogram which graphically displays the clustering results. To make comparisons between dendrograms easier, the graphic is scaled so that the smallest coefficient has a nominal value of 1 and the largest 25. In this way, the relative distance between clusters can be visually judged as the number of groups is reduced from n to 1.

5.6 Estimating Method Precision

The test protocol included analysis of method blanks. These results can be used to estimate manual method precision by combining the analytic results for the blank train with the sample volume and stack gas oxygen content of the train closest in time.

Laboratory quality assurance involves confirming that the data are reproducible and representative. Reproducibility is usually expressed for duplicates as the Relative Percent Difference [RPD] or simply Percent Difference [PD] and as Standard Error [SE] for triplicated and greater replication.

$$RPD = 100 * |\chi_1 - \chi_2|/([\chi_1 + \chi_2]/2) \quad [9]$$

$$SE = 100 * STD(\chi)/\langle\chi\rangle \quad [10]$$

where :

χ is the analytic concentration; 1 and 2 designate the first and second analytic run results;

$|\,|$ denotes the absolute value;

STD is the sample standard deviation; and

$\langle\,\rangle$ is the arithmetic average of all values of χ.

Calibration Errors are calculated for all reference materials and QA samples processed along with the samples as the ratio of the measured value, χ, to the standard value, SV.

$$CE = 100 * \chi/SV \quad [11]$$

Equation [11] has multiple additional uses. It is used to calculate the accuracy with which reference material results are obtained. When a sample has been spiked, it is also used to calculate the percentage of spiked material that is recovered.

Following traditional analytic practice, the DL is three times the between-train variability and the LOQ, that is the concentration needed to provide assurance that the result is real and not a statistical aberration, is

ten times the between-train variability. For particulates, the DL is 2 mg/dsm^3 @ 7% O_2 and the LOQ is 6.8 mg/dsm^3 @ 7% O_2. For total dioxins and furans, the DL is 0.4 ng/dsm^3 @ 7% O_2 and the LOQ is 1.3 ng/dsm^3 @ 7% O_2. DLs and LOQs for this test program cannot be estimated for lead, cadmium and mercury since the blank train results were all below analytic detection limits.

A review of the particulate data indicates that many of the results are less than the LOQ and should be taken as best estimates, rather than precise values. The dioxin data were all above the LOQ.

5.7 Calculating Statistical Emissions Limitations

Emissions limitations are the not-to-be-exceeded values found in permits and regulations. While they have historically been negotiated values, statistical methods can be used to establish levels below which no prudent person would set an emission limitation. The upper tolerance limit [UTL] is a statistical bound designed to contain a specified percentage of future tests at a given statistical confidence level. For example, the available data could be used to calculate the UTL which is equivalent to setting a limit to contain 99 percent of all future test results with 95 percent confidence. An alternative bound is the upper prediction limit [UPL], a statistical bound that is designed to contain a specified number of future tests at a given statistical confidence level. For example, the available data could be used to calculate the UPL which is equivalent to setting a limit to contain the next 5 emission test results with a of 95 percent confidence, the maximum number of annual tests that would occur between Title V operating permit renewals for MWCs.

For this study, we have chosen to calculate the UPL. For any inlet concentration, the outlet stack concentration can be determined:

$$\chi_o = \chi_I * (1 - \eta_{UPL}) \qquad [12]$$

where:

χ_o is the outlet concentration

$\eta_{UPL} = 1/(1+\exp \zeta)$

$$\zeta = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + t_{(n-m+1,1-\alpha/2T)}\{(1/r + 1/n)[\Sigma(X_i-\langle X_i\rangle)^2/(n-1)S_i^2]\}^{1/2}\ SER \qquad [13]$$

$t_{(n-1,1-\alpha/2T)}$ is the studentized t statistic for n-1 degrees of freedom and $1-\alpha/2T$ statistical significance level

α is the normal statistical confidence level -- 95 percent in 40 CFR 60

T is the number of future tests to be contained -- 5 for annual testing throughout a Title V permit validity period

r is the number of runs to be included in a test average -- 3 in 40 CFR 60

n is the number of data points used in fitting the UPL regression equation

m is the number of coefficients fit

$<X_i>$ is the average value for the X_i used in fitting the UPL regression equation

S_i is the standard deviation of the X_i used to fit the UPL regression equation, and

SER is the standard error of the regression -- the standard deviation of the differences between the predicted and test values

Curves displaying expected emission limitations for PCDD/Fs, Hg, HCl and SO_2 were developed using Equation [12]. Because the inlet concentration (χ_i) is not known on a run-by-run basis since the close-coupled nature of the DCERF precluded simultaneous inlet and outlet concentration sampling, the regression excluded this term. Consequently, inlet concentration is effectively assumed to be constant through out testing and its contribution is subsumed by the overall constant, a_0.

5.8 Demonstrating MWC Condition Similarity Between Tests

The information collected is real data. As a result, it would be surprising to find the same numeric value for the average or median result for each test period. Each test period average or median is made up of individual measurements which provide a way to determine if two different numeric results are really different.

A graphical ANOVA method based on the work of Gabriel (1978) was used to make the comparisons. This method avoids having to determine the form of the underlying data distribution. Gabriel points out that graphical comparisons can be made if half the critical distance[4] between means—the separation that indicates a difference—is plotted on each side of the data centroid for individual sets. Box plots are a convenient way to perform the comparison. For each data set, the mean is displayed in the center of a box whose ends contain half the data. Extreme values are shown on whiskers as long as the data are within with two box lengths. Points farther out are flagged as being Extreme or Outlying. In the case of multiple comparisons, the length is determined by Hochberg's (1972) GT-2 method using the appropriate Studentized Maximum Modulus Distribute [SMMD] and the number of degrees of freedom in the smallest data set; 16 for a 4-hour test worth of 15 minute averages. If we think in terms of a box plot like that shown in Figure 5-1, which is centered on the median and upper and lower points of the IQR which correspond to ±0.6745 standard deviations in the normalized distribution, the SMMD is bounded as follows for the ends of the IQRs overlapping:

$$0.6745\ (2n)^{1/2} < \text{SMMD} < 1.349\ (n)^{1/2} \qquad [14]$$

and, for the median of one set being inside the IQR of the other

$$0.6745\ (n/2)^{1/2} < \text{SMMD} < 1.349\ (n)^{1/2} \qquad [15]$$

for n data points in the smaller set being compared. The left hand side of Equations [14] and [15] apply when about the same number of data points are in each data subset. The right hand side applies where a set with a small number of data points is being compared to a large data set. For the number of 15-minute average DCS and CEMS data points in the runs, an IQR touching or overlapping indicates there is no difference between the runs at the 90 percent confidence level. As long as the test IQRs are touching the be-

[4] The critical distance is conceptually the difference between two means needed to determine that they do not both come from the same data set—that is, they are numerically different, but practically the same. For a simple two parameter comparison, this distance is $t\ S/n^{1/2}$ or the standard error (uncertainty) of the mean.

fore and after test period characteristic IQRs the facility is exhibiting similar performance during test periods and normal operations.

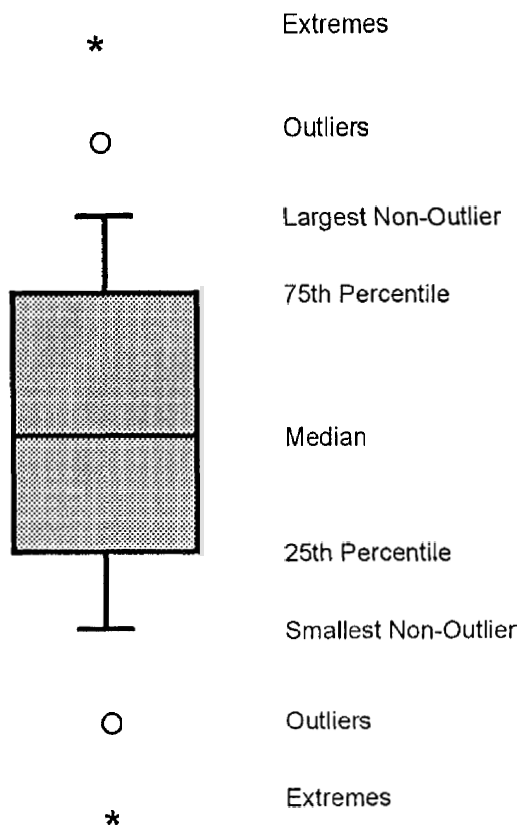


Figure 5-1 Box plot showing displayed data characteristics.

SECTION 6—QUALITY ASSURANCE PROJECT PLAN AND RESULTS

6.1 Sampling Procedures

The project was conceived to measure actual emissions performance for acid gases and those pollutants listed in 40 CFR 60 Subpart Cb Emissions Guidelines for MWCs at existing facilities. Stack sampling was undertaken using the following procedures or modified procedures:

- EPA Method 29 Determination of Multiple Metals Emissions from Stationary Sources (40 CFR 266, Appendix IX, Section 3.1) including the determination of front-half particulate matter. The laboratory recovery was modified for mercury recovery from an aliquot of the acidified hydrogen peroxide impingers by adding potassium permanganate to neutralize the excess peroxide which appears to cause a low bias of Method 29 compared to Method 101A for some sources.

- EPA Method 23 - Determination of Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans from Stationary Sources. (40 CFR 60, Appendix A).

- EPA Method 26 - Determination of Hydrogen Chloride from Stationary Sources. (40 CFR 60 Appendix A).

- EPA Method 6C and 7E Continuous Emission Monitoring 40 CFR 60 Appendix B CEMS procedures for NO_x (Chemiluminescence) and SO_2 (non-dispersive ultra violet-NDUV).

- Davis County Resource Recovery Facility, Ash Sampling Protocol, Revision 2, for combined ash and ESP residue grab samples.

The discussions that follow outline the QA/QC procedures associated with the sampling and recovery methods used for the various procedures. Some general procedures were used for all sampling and these are summarized before the detailed discussions. Actual method details are provided in Volume III.

American Chemical Society [ACS] pesticide grade Chemicals and Type I Reagent water were used for all metal and acid gas sampling trains and analysis. Pesticide grade solvents and HPLC grade water were used for trace organic sampling train preparation and sample analysis. Filters were bought to conform to Method 29 purity requirements of <1.3 mg/in^2 of any metal of interest.

Reagents, filter, and sorbent quality were checked for contamination. In most of the cases, this involved analysis of the reagents and filters using the procedures, analytical methodologies and detection limits applied to the actual samples.

Proofing was done to make sure that measured responses characterize a source and are not residue from a previous test. Proofing involved analyzing samples obtained by recovering the cleaned components per the Reference Method 23 procedures. Since there are no proofing requirements in Method 23, the proofing samples were analyzed following the procedures employed by the USEPA and Environment Canada in their joint effort at the Mid-Connecticut Resource Recovery Facility. PCBs and PAHs were selected as proofing surrogates because experience shows that trains free of these materials are also PCDD/F free. Also, PCB and PAH analyses are much less expensive than PCDD/F analyses, so they are suitable for routine Quality Assurance Activities. Acceptably clean systems had maximum contamination levels below 50 ng/train for total PCBs and PAHs below background contamination.

CEMS calibration gases meet 40 CFR 60 Appendix F Cylinder Gas Audit [CGA] Audit Standards and were National Institute of Science and Technology [NIST] traceable.

Before conducting formal emission testing, preliminary tests were conducted to:

- establish sampling conditions; and
- identify any adverse conditions at the sampling locations or in gas flow and develop approved alternative procedures.

Duct inside diameter and flue gas moisture content, static pressure, velocity pressure profiles, temperature profiles and combustion gas composition were measured for each temperature condition.

6.2 Analytic Procedures

All analytic procedures followed the protocols specified by the method. The analytic laboratory methods employed are described in Table 6-1.

Table 6-1 Analytic Methodologies for Stack Samples.

COMPONENT	METHOD	REFERENCE
Particulate Material	Gravimetric	Method 5
Metals	Inductively Coupled Plasma Atomic Evaluation Spectroscopy (ICAP): Cd, Pb	Method 29 & SW-846 6010
Mercury	Cold Vapor Atomic Absorption (CVAA)	Method 29 & SW-846 7470
Hydrogen Chloride	Ion Chromatography (IC)	EPA Method 26
Dioxins and Furans	High resolution gas chromatography/high resolution mass spectrometry (high resolution GC/MS)	EPA Method 23 & SW-846 8290

6.2.1 Method 29 Train for Particulate, Metals & Mercury Analysis

The analytical procedures for measuring the trace metals in samples collected by the Method 29 train samples are based on analyzing the metals formed upon dissolution in the impinger reagent and digestion of the metals associated with the particulate fraction. The sampling train is described in Table 6-2.

Samples were acquired by isokinetically sampling the flue gas as the stack was traversed. Particulates deposit in the probe and are captured on the filter. Very fine particulate phase and gaseous metals that penetrate the filters are caught in a series of liquid filled impingers. The first pair of impingers contains acidified hydrogen peroxide and catches most metals; the second pair contains acidified potassium permanganate solution which is designed to capture elemental mercury.

Sample gas was drawn through the nozzle and probe and then through a heated quartz filter. Particulate matter collected on the filter and in the probe was weighed and then analyzed for the metals of interest. The impingers were weighed before and after the test run for gravimetric moisture determination.

Leak-checks on the assembled train were performed before and after each sampling run and during port changes. In the event that any portion of the train was disassembled and reassembled (i.e., filter change),

leak-checks were performed prior to disassembling the train and resuming sampling. All leak-checks and leakage rates were documented on the relevant field test data sheet.

Table 6-2 Summary of Method 29 Particulate Material, Metals and Mercury

TRAIN CONFIGURATION	
Nozzle	Quartz
Probe Liner	Quartz
Filter	Quartz fiber filter without organic binders and background metal content of < 1.3 mg/m^2
Impinger Solutions	1. Empty 2. HNO_3/H_2O_2 (100 mLs) 3. HNO_3/H_2O_2 (100 mLs) 4. Empty 5. $KMnO_4/H_2SO_4$ (100 mLs) 6. $KMnO_4/H_2SO_4$ (100 mLs) 7. Silica Gel (200 - 300 g)

SAMPLE RECOVERY COMPONENTS

CONTAINER	CONTENTS	ANALYSIS REQUIRED
1	Filter	Particulate, Metals and Hg
2	Acetone Front Half Rinse (100 mL)	Particulate and Metals
3	Probe Rinse 0.1 N HNO_3 (Front Half Rinse) (100mL)	Metals and Hg
4	Back Half Filter, Impinger Contents (1,2,3) and Nitric Acid Rinses (100 mL)	Metals and Hg
5A	Impinger 4 content and 100 mL HNO_3 rinse Impinger Contents (5,6) and 100 mL $KMnO_4$ rinses	Mercury
5B	HCl (25 mL) rinse of Impingers 5 & 6 in 200 mL of DI water	Mercury
5C		Mercury

SAMPLE STORAGE CONTAINERS

- 1000 mL or 500 mL glass amber (wide mouth) sample containers with Teflon lined caps liquid samples and blanks
- petri dish for filter

SAMPLE ANALYSES SCHEME

PARAMETER	METHOD	COMBINED LAB SAMPLE
Particulate Material Determination	Gravimetric	Containers 1 and 2
Metal Analysis Cd, Pb Hg	ICAP Cold Vapor AA	Containers 1, 2, and 3 Containers 1, 2 and 3 Container 4 Containers 5A, 5B & 5C

BLANKS

Reagent Blanks Collected in the Field and Held for Possible Analysis:

Acetone	100 mLs	
0.1 N HNO_3		200 mLs
5% HNO_3/10% H_2O_2	200 mLs	
Acidified $KMnO_4$	300 mLs	
8 N HCl/DI Water	50 mLs	
Filter Blank		50 mLs

Blank Train:

Taken through all the steps from preparation to recovery without actual sampling. Four blank trains were collected and analyzed during the test program.

Preparatory activities for this train include equipment calibration and filter weighing, standard to Method 29. This train's glassware and associated sample containers were precleaned, as detailed in Volume III. Recovery followed the method. Reagent and filter blanks were collected in the field three times during the field test.

Inductively-coupled argon plasma emission spectroscopy analysis of the hydrofluoric and nitric acid digested sample extracts were performed for all metals except mercury. Mercury was determined by cold vapor atomic absorption.

The acidified $KMnO_4$ solutions were prepared fresh daily and stored at 4°C in a glass amber bottle. The $KMnO_4$ impingers were wrapped in aluminum foil. Stock $KMnO_4$ solutions and sulfuric acid solutions were provided fresh weekly. The $KMnO_4$ was not acidified until the test day.

A gravimetric determination of particulate samples (front-half acetone rinse and the filter) collected from the particulate/metals train was performed prior to metals analysis following the procedures outlined in Method 5. The gravimetric analysis required measuring the weight gain on the particulate filter and the residue in the acetone rinse of the front-half train components. Back half condensibles could not be determined without invalidating the metals samples. Samples were repeatedly desiccated and weighed to a constant weight of ± 0.5 mg.

At least one duplicate and one spiked sample were analyzed in the laboratory with every 20 samples to verify precision of the method and one QC sample (mid point of calibration curve) with every 10 samples. Matrix spike samples (one of each with every 10 samples) were performed to document the effect of the sample matrix on the analysis. Duplicate sample analyses (one with every 10 samples) were performed to determine analytical precision and method blanks serve to assess the degree of background contamination.

Separate analytic results were reported for front-half, back-half and potassium permanganate impinger catches, but combined to determine emitted concentrations for each run. Analytic results were reported in accordance with ASTM D 4210-83; that is, results less than 3 blank standard deviations (instrument noise) were reported as BDL and those between the BDL value and the LQL (laboratory quantification limit or 10 blank standard deviations) were reported as EMC (estimated maximum concentration or Tentative).

6.2.2 Method 23 Train for PCDD/F Analysis

The analytical procedures for determining the quantity of PCDD/Fs present in samples collected in the Method 23 train are based upon the use of selected ion monitoring (SIM) GC/MS. Analysis follows a complex series of extraction and clean-up procedures used to recover the analytes from the particulate catch, sorbent cartridge and impinger contents of the sampling train.

Like the Method 29 train, Method 23 uses a modified Method 5 sampling train. Isokinetic samples were withdrawn as the train traversed the stack. The train is described in Table 6-3.

The sample train consisted of a heat-traced probe with a nickel-plated, stainless steel nozzle, and attached thermocouple and pitot tube. The glass probe was maintained at a temperature of 120°C ±14°C. After the probe, the gas passed through a heated glass fiber filter. Downstream of the heated filter, the sample gas passes through a water-cooled module, then through a sorbent module containing approximately 30 to 40 g of XAD-2 resin (pack trap). The XAD module, which was kept at a temperature below 20°C, was followed by a series of four impingers. The XAD inlet temperature was monitored to ensure that the temperature of the flue gas sample entering the module is maintained below 20°C. The first impinger was con-

nected to the outlet of the XAD module, and modified with a shorter stem so that the sample gas did not bubble through the collected condensate.

The first impinger was empty, the second and third impingers contained 100 mL of HPLC grade water, the fourth was empty and the fifth contained a known weight of silica gel. The impingers, condenser and XAD-2 resin module were weighed prior to assembling the sampling train to permit gravimetric moisture determination. All connections within the train were glass or Teflon; no sealant greases were used. The impingers were followed by a pump, dry gas meter, and a calibrated orifice meter.

Prior to sampling, all gas-contacting components of the train were washed with Alconox and water and thoroughly rinsed with solvents. All trace organic train components and sample containers were proof rinsed, the rinses were analyzed, and components and glassware were deemed free of contamination prior to use.

Table 6-3 Summary of EPA Method 23 PCDD/F

TRAIN CONFIGURATION		
Probe	Quartz with quartz liner	
Filter	Glass fiber filter without organic binders	
Resin	Amberlite XAD-2	
Impinger Solutions	1. empty - short stemmed	
	2. R.O. Water	(100 mLs)
	2. R.O.Water	(100 mLs)
	3. Empty	
	4. Silica Gel	(200 - 300 g)

SAMPLE RECOVERY COMPONENTS		
CONTAINER	CONTENTS	ANALYSIS REQUIRED
1	Filter	Trace Organics
2	Acetone Rinse (3x); DCM Rinse (3x) Front Half, Back Half and Condenser Coil	Trace Organics
3	Toluene Rinse (3x) Front Half, Back Half and Condenser Coil	Trace Organics
4	Amberlite XAD-2	Trace Organics
5	Impinger Contents and R.O water rinses (3x)	Trace Organics

SAMPLE STORAGE CONTAINERS

- 1000 mL or 500 mL glass amber (wide mouth) sample containers with Teflon lined caps
- Glass petri dishes for filters
- clean aluminum foil to wrap XAD-2 trap and filled storage containers

SAMPLE ANALYSIS SCHEME		
	METHOD	COMBINED LAB SAMPLE
	GC/MS High Resolution	One sample analysis per train (Containers 1, 2, 3, 4, 5 and 6)

BLANK TRAIN

Blank Train: Taken through all the steps from preparation to recovery with leak-check volume ambient conditions sampling. Four blank trains were collected and analyzed during the test program.
Field Blanks: Combined acetone/hexane, combined water/glycol, XAD-2 trap, glass fiber filter. Samples collected and archived; analyzed if necessary.
Field Spiking: Spiking of the resin cartridge will take place at Analytic Laboratory prior to sampling and will include the following 5 labeled compounds:

$^{37}Cl_4$-2,3,7,8-TCDD
$^{13}C_{12}$-1,2,3,4,5,7,8-HpCDF
$^{13}C_{12}$-2,3,4,7,8-PCDF
$^{13}C_{12}$-1,2,3,4,7,8-HxCDF
$^{13}C_{12}$-1,2,3,4,7,8,9-HpCDF

Sampling train leak-checks were performed before and after each sampling run and during each port change. The sample train leak-checks and leakage rate (where applicable) were documented on the field test data sheet for each respective run. Following completion of each run, the trains were taken to a recovery area on-site, recovered and the analytic samples secured for transportation to Analytic Laboratory. All recovered samples were stored in a refrigerator at 4°C immediately following sample recovery.

Three Method 23 sampling trains were assembled, leak-checked and recovered to verify background contamination. The blank trains were handled at the sampling site in the same manner as the test trains, except that the only gas drawn through the blank train is ambient air equivalent to that induced during leak-checks.

The filter section and resin were extracted separately and combined prior to clean-up. Based on laboratory experience, the following minor modifications to the written procedures were employed:

- toluene was substituted for benzene as a solvent; and
- for solvent exchange into hydrocarbon solvent, toluene replaced hexane.

A single analysis was performed for combined recovered and cleaned extracts from each train. To monitor the extraction, clean-up, and analysis of trace organic samples, labeled surrogates were added to field samples, field and laboratory blanks, and matrix spikes prior to extraction. One set of labeled surrogates was added in all the Soxhlet extraction steps. A second set of the labeled surrogates was added to impinger samples from the Method 23 train during extraction.

Target recoveries for surrogate compounds were well within EPA's 70 to 130 percent range with the precision of blind duplicates analysis better than 50 percent. Since these surrogates are used to adjust the results for native PCDDs and PCDFs, low recoveries do not invalidate the data, but do result in higher than desired detection limits and mathematical adjustments.

The labeled surrogates added for Soxhlet extractions were:

2,3,7,8-TCDD-$^{13}C_{12}$
1,2,3,7,8-PeCDD-$^{13}C_{12}$
1,2,3,6,7,8-HxCDD-$^{13}C_{12}$
1,2,3,4,6,7,8-HpCDD-$^{13}C_{12}$
OCDD-$^{13}C_{12}$

The following internal standards were used:

PCDD/PCDF - 1,2,3,4-TCDD-$^{13}C_{12}$ and 1,2,3,4,7,8-HxCDD-$^{13}C_{12}$

Field spiking of the XAD-resin—prior to sampling—was performed. Each resin cartridge was spiked with:

$^{37}Cl_4$-2,3,7,8-TCDD
$^{13}C_{12}$-1,2,3,4,5,7,8-HpCDF

Validated blank data demonstrated that the extraction and clean-up systems were free of contamination. Method blanks and matrix blanks were analyzed with every other extraction to demonstrate contamination below the target detection limit.

6.2.3 Method 26 Sampling Train for HCl

The analytical determination of anions collected in samples caught in acidic and alkaline impinger solutions is based on ion chromatographic techniques. The acid species (HCl) is caught in the first pair of acidic impingers and the molecular gas (Cl_2) is caught in the alkaline impingers. The sampling train consists of a heated glass probe and filter followed by a three way stop clock and 30 mL midget-impingers as outlined in Table 6-4. The first two impingers contained 15 mLs of 0.1 N H_2SO_4 while the third and fourth impingers contained 15 mLs of 0.1 N NaOH. A final impinger containing silica gel was placed after the fourth impinger to protect the dry gas meter and pump.

The train was leak-checked by plugging the probe inlet and turning on the sample pump to pull a vacuum of 10 inches of Hg. The needle valve was turned off and the vacuum remained stable for 30 seconds for a successful leak-check. The sampling system was leak-checked at the beginning and end of each run.

HCl was determined using ion chromatography. Aqueous impinger solutions were injected into a stream of 4-hydroxybenzoic acid elutent prior to entering a separation column where the anions present are separated based on their relative affinities for the strong base anion exchangers. The separated anions are measured on a conductivity detector and identified based on their retention time relative to known standards. Quantification is based on peak area using electronic integration. Calibration curves were composed of a blank and a minimum of three standards. Duplicate QC samples and check standards were run with every group of ten samples.

Table 6-4 Summary of EPA Method 26 Hydrogen Chloride (HCl)

TRAIN CONFIGURATION		
Probe Liner	Glass	
Filter	25 mm Teflon, glass mat or Pallflex filter	
Impinger Solutions	1. 0.1 N H_2SO_4	(15 mL)
	2. 0.1 N H_2SO_4	(15 mL)
	3 0.1 N NaOH	(15 mL)
	4. 0.1 N NaOH	(15 mL)
	5. Silica Gel or Drying Tube	(200 - 300 g)

SAMPLE RECOVERY COMPONENTS		
CONTAINER	CONTENTS	ANALYSIS REQUIRED
1	Impinger 1& 2 and DI Water Rinsings	HCl
2	Impinger 3 & 4 and DI Water Rinsings and sodium thiosulfate	Cl_2

SAMPLE STORAGE CONTAINERS
- 100 or 250 mL HDPE sample container with Teflon lined screw lids

SAMPLE ANALYSES SCHEME		
PARAMETER	METHOD	COMBINED LAB SAMPLE
HCl	Ion Chromatography	Container 1
CL_2	Ion Chromatography	Container 2

BLANKS	
Reagent Blanks Collected in the Field and analyzed:	
0.1 N H_2SO_4 diluted with DI water	30 mL + DI water
0.1 N NaOH diluted with DI Water	30 mL + DI water

6.2.4 CEMS for Combustion Gases and Criteria Pollutants

The concentrations of the following combustion gases were monitored on a continuous basis using continuous emissions monitors:

- carbon monoxide (CO),
- oxygen (O_2)
- sulfur dioxide (SO_2), and
- nitrogen oxides (NO_x).

The instrument specifications are provided in Table 6-5.

A sample of the flue gases was drawn through a stainless steel tube inserted in the exhaust gas flow, filtered to remove particulate material, then transferred by a Teflon line to the gas conditioning unit and individual analyzers. The Teflon sample line was heated to at least 160°C.

Prior to the start of testing, the following preliminary assessments and calibrations were made:

- The sampling probe was traversed across the CEMS sampling location to check for stratification. Stratification was deemed absent when all points were within 10 percent of the average. A three-point calibration of the instruments through the complete collection system was performed by directing calibration gas to a point of entry immediately after the sampling probe and to the analyzers directly.

- Reproducibility checks involved three replicate analysis of calibration gas at each point.

- Instrument linearity checks were done prior to going on-site and after test program completion. Calibrations were at three points plus a zero with a resultant r = 0.995 which were deemed acceptable.

- A sample recovery check (system bias check) was conducted prior to and daily during testing. Calibration gases were introduced at the sample probe inlet upstream of the sample transport pump and directly to the analyzers. Greater than 90 percent recovery was achieved.

Differences between the readings were interpreted to be losses in the transport or conditioning system.

Table 6-5 Combustion Gas Analyzer Specifications

ANALYZER	MODEL	PRINCIPLE	RANGE OF OPERATION
Nitrogen Oxides	Western Research Series 900	Chemiluminescent	0-5000
Sulfur Dioxide	Western Research Series 900	NDUV	0-500 + 0-5000
Hydrocarbon	JUM Engineering VE7	FID	0-10
Oxygen	Western Research Series 900	NDUV	0-25
Carbon Monoxide	TECO 48	Gas Filter Correlation	0-200

6.3 Residue Sampling and TCLP Analysis Procedures

Composite samples of ESP residue, acid gas reagent and activated carbon were collected near the end of each condition's run.

Grab samples of ESP residue were taken from the fly ash screw conveyor that connects the bottom of the baghouse hoppers to the ash bunker. Incremental grab samples of the trona and activated carbon being used during any test were obtained throughout the day, composited and archived in a 1 liter wide mouth glass jar fitted with a polyvinyledine chloride sheet lined lid.

At the present time, no analyses have been performed on the trona, PAC or ESP ash samples. They are archived. In addition, DCERF collected combined ash samples whenever combined ash was removed from the facility. A total of 10 samples were obtained and analyzed for TCLP metals and organics following the regulatory protocols.

The highly variable (heterogeneous) nature of combined ash residues means that correct characterization of incinerator residues is a difficult and exacting process. Accurate characterization begins with obtaining representative samples of the combined ash residues leaving the facility. It continues through preparation of representative laboratory subsamples. Finally, the laboratory procedures must follow the prescribed regulatory methods.

At DCERF, combined ash is accumulated in a segmented concrete ash storage bin. This bin is also called a bunker or pit. It has four separate segments. Bottom ash is extruded from water filled ram dischargers at the end of the grate onto vibratory conveyors. As the ash moves the short distance to the bin, boiler tube bank ash is deposited on top of the bottom ash. APCS residue is moved from the hoppers under the ESPs to the bin in closed screw conveyors. The APCS residue is moistened prior to being discharged into the segmented bin opposite the bottom ash from the same boiler.

In the segmented bin, combined residues are mixed as they are moved from the first and third segments (A and C) to the central bin (B). Several times a 12 hour shift, the residue is transferred to the larger end bin (D) for storage until it is loaded into covered dump trucks.

Residues are out-loaded to covered dump trucks 6 to 12 hours per day, 3 to 6 days per week. Out-loading, like between bin transfer and mixing, is accomplished using a clam shell grapple. Residue is dug out of out-loading bin D and discharged into the dump trucks through a load-out hopper. The truck pulls forward, is covered and leaves the fully enclosed ash area. After weighing, the truck goes to the landfill and discharges the combined ash at the bottom of the working face.

Combined ash is sampled as it is withdrawn from bin D for truck loading. Daily samplings were separated into two periods by equally dividing the number of hours residue hauling was expected to occur in half. Sample increments were taken every hour--on a random, sequential basis--and composited to create a 5 gallon sample per residue hauling day. This is a periodic random sampling plan as described in SW-846.

Once each hour, the grapple was stopped at a safe location to remove a sample as it traversed from the out-loading bin D to the discharge hopper. Any loose ash was knocked off the sampling shovel and rinsed in a bucket of water filled from the source used to fill the ash quench system.

Because the clam shell closing action causes fine material to sift and roll from the center of the residue pile as the grapple closes, a clean shovel was used to remove the top 4 to 6 inches of the residue from the center of the grapple. This potentially non-representative material was put to the side of the grab. Then, a shovel full of residue from the center of the cleared area is retrieved. As representative a sample as possible, including oversized and bulky items, was taken. In the event the sampling area was blocked by a large item (i.e., a water heater or muffler), another adjacent area was uncovered from which to take the sample.

6.4 Process Data Acquisition

Basic system operating data were continuously recorded by the DCERF Data Historian, an integral part of the Provox Operating System. The operating data were provided as an Excel file and summarized as run maximums, minimums and averages. Baseline operating characteristics were also developed to verify that the facility was in normal operating condition during the testing. Operating data were provided for a week prior to start of testing; throughout the test period, and for more than two weeks immediately following test.

Continuously recorded process parameters for the tested incinerator were:

- Gas temperatures: furnace throat, boiler top temperature (first pass), superheater inlet and outlet, economizer inlet and outlet, ESP inlet, and ESP outlet (stack).
- Boiler steam: temperature, flow and pressure.
- Boiler feed water characteristics: flow and temperature.
- Spray water characteristics: flow and temperature.
- Atomizing air pressure.
- Incinerator and ESP draft.
- Opacity, plant CEMS (CO) and plant PEMS (NO_x & SO_x) on the other unit data.
- Stoker operating characteristics: feed ram cycle and grate cycle times.
- Acid Gas reagent and PAC feed rates.

6.5 EPA Level IV QA/QC Procedures

The overall objective of the sampling and analysis effort was to provide data that were precise, accurate, comparable, representative and complete. The definitions for these criteria and how compliance with them was assessed are described below.

6.5.1 Precision, Accuracy and Completeness

The two aspects of data quality of primary concern are precision and accuracy. Precision, as defined in "Guideline and Specifications for Preparing Quality Assurance Project Plans" (U.S. EPA QAMS-005/80), is "a measure of mutual agreement (or variability) among individual measurements of the same property, usually under prescribed similar conditions". Various measures of precision exist depending on these conditions. This term is independent of the error (accuracy) of the analyses and reflects only the degree to which the measurements agree with one another, not the degree to which they agree with the "true" value for the parameter measured.

Quality control procedures, such as control sample analyses and replicate analyses, represent the primary mechanism for evaluating measurement data variability or precision. Control sample analyses are used to define repeatability, replicate analyses are used to define analytical replicability, and results for replicate samples may be used to define the total variability (replicability) of the sampling/analytical system as a whole. QC objectives for laboratory control samples (prepared QC standards) and duplicates are outlined in Table 6-6.

The QA/QC objectives for precision, accuracy and completeness established for each major compound measured are considered guidelines. For a measurement system, if all QC data meet these objectives, the test results are judged as having acceptable quality. When specific QC criteria are not met, the data are flagged and the acceptance left to the technical judgment of the data user and the regulatory agency.

Data that failed to meet the guidelines were inspected for errors and a case-by-case determination made of representativeness. Based on the findings, the data were either retained for interpretation or rejected as not meeting QA/QC criteria.

Table 6-6 QA Objectives for Precision, Accuracy and Completeness for Analysis of Field Samples

PARAMETER	PRECISION[a] (%)	ACCURACY[b] (%)	COMPLETENESS[c] (%)
Dioxins & Furans (EPA Method 23) Trace Organic train	NA[d]	40 - 130	90
Metals (EPA Method 29)			
Metals, Particulate	NA[d]	80 - 120	90
Aqueous (impinger solutions)	< 20	80 - 120	90
Solids (ash)	< 20	50 - 130	90
Acid Gases (HCl) (EPA Method 26A) Aqueous (impinger solutions)	< 20	80 - 120	90

[a] Expressed as the average percent difference between replicate field sample analytical results.
[b] Expressed as the observed versus the expected value of matrix spike and matrix spike duplicate samples. For trace organic analysis, surrogate standards will be used to monitor for accuracy.
[c] Expressed as the percentage of analyses deemed valid over all planned analyses of this type.
[d] Replicate stack gas samples will not be taken.
NA - not acceptable.

Table 6-7 QA Objectives for Precision, Accuracy, and Completeness for Sampling Measurements (Guidelines)

MEASUREMENT	PRECISION (RSD) (%)	ACCURACY[a] (%)	COMPLETENESS (%)
Continuous Methods			
Oxides of nitrogen	± 20	15	95
Sulfur dioxide (UV)	± 20	15	95
Manual Methods			
Particulate Matter	12	ND[b]	90
Metals, HCl	± 15[c]	± 15[c]	90
Gas temperature (type K thermocouple)	ND	± 3[d]	95
Dioxins	± 50[c]	± 50[c]	90

RSD - Relative Standard Deviation of replicate analysis of calibration gases.
[a] Relative accuracy will not be determined during this test program.
[b] Not determinable within limits of method precision.
[c] Analytical phase only.
[d] Relative accuracy compared to NBS-traceable thermometer.

6.5.2 QA Results

All reference method samples were collected under isokinetic conditions. That is, the velocity in the probe tip was ±10 percent of the velocity of the surrounding gas stream. This condition prevents sample bias by misrepresentation of large particles which do not follow the gas stream (low percent isokinetic ratio) or small particles that do (high percent isokinetic ratio).

The CEMS were cylinder gas zero and span calibrated on schedule. Zero and span corrections were applied to the 10 second data before aggregating to 15 minute averages. Zero and span corrections were less than 3 percent.

At the analytic laboratory, an aliquot was not withdrawn from the T12 front-half (probe rinse plus filter) digestate for mercury analysis prior to adding the digest to 90 percent of the acidified peroxide impingers. As a result, no sample was available for front half (probe plus filter) for this run and a mercury distribution cannot be calculated.

Due to an error, two fiberglass filters that did not meet purity requirements were sent to the field along with the specified high purity quartz filters. One fiberglass was used in a Method 29 train; fortuitously, the other become a blank. Analysis of the fiberglass filter indicates that the metal concentrations for CAA Section 129 pollutants are marginally acceptable. A blank correction equal to the blank value was used because the companion quartz filters displayed negligible Section 129 metal concentrations. Some of the non-Section 129 metals reported in Appendix A are substantially affected by this error, but the blank correction brings them generally in line with the balance of the data. Users of these data (run T15) are cautioned to review the laboratory report in Volume II of this report to make sure that the data are suitable for their intended purposes.

For one series of mercury tests, the laboratory spike was too low relative to native (sampled) mercury concentrations to determine spike recovery values. A high sulfur interference was experienced for a few non-Section 129 metals and no result is provided for one cadmium proof run. The method proofs (an extra recovery of a used train) indicated that recoveries generally exceeded 99 percent for all metals tested.

Four of the proof rinses collected after each Method 29 run were analyzed to confirm recovery. The section 129 metals Pb and Cd displayed 95-99+ percent recoveries *. Among the non-Section 129 metals, calcium, chromium, iron, manganese, sodium, potassium, strontium and antimony displayed occasional low recoveries. One antimony recovery (53 percent) was less than the 80 percent target. Three of the chromium recoveries were low (31 percent, 57 percent and 65 percent). The general recovery pattern indicates that the problem may be sample container leaching of metals found in brown glass. These proof samples were digested and analyzed after the rest of the analytic work was complete, so they had about two months to leach metals, compared to the 1-2 weeks experienced by the field samples. Users of the data in Appendix A are cautioned to review the analytic laboratory report in Volume II of this report and make their own judgment regarding the need for any recovery adjustment.

Two of the Cl_2 samples displayed excessive variance. The results were within normal QA criteria, but outside the precision limit set for this work. The problem is noted to indicate that the comparatively high Cl_2 results for Runs T6 and T8 should be taken as order-of-magnitude rather than precise results.

* Sample mass divided by the sum of the sample and proof mass.

The reported 2,3,7,8 TCDF values are from the standard DBS column. Confirmatory analyses were done using the SP2331 column which consistently yielded 2,3,7,8 TCDF values between 25 and 34 percent of the values reported in Table 3-1 and Appendix A. Toxic equivalents calculated using the DBS column results overstate the toxicity of the mixture by 30 to 170 percent. The total dioxin quantity is not materially affected (a 1 to 3 percent overstatement).

PCDD/F spike recoveries were within the regulatory QA/QC limits. We note, however, that they generally ranged between 100 and 130 percent instead of varying about 100 percent. Consequently, there may be a problem with the laboratory's spiking system. The spikes may be 15 percent greater than intended.

Toluene rinse method proof samples were analyzed for three runs. The toluene rinses contained less than one percent of most isomers. Up to five percent of the OCDD was found in the proof rinse which translates to a maximum of 0.5 percent low bias in total PCDD/F concentrations. The maximum low recovery has a negligible impact on toxic equivalent calculations since the OCDD concentration is comparatively small in the first place and the ITEQ weighting factor is 0.001.

SECTION 7—REFERENCES

1. Gabriel, K. Ruben, "A Simple Method of Multiple Comparisons of Means," *J. Am. Stat. Assoc.*, Vol. 73, No. 364, p. 724, December, 1978.
2. Heath, "Design and Installation of Powdered Activated Carbon Storage and Injection Systems for Municipal Solid Waste Incinerators," Proceedings of the 88th Annual AWMA Meeting, Paper 95-RP-147B.01, San Antonio, Texas, June 1995.
3. Hochberg, Y., "Some Generalizations of the T-Method in Simultaneous Inference", J. Mulivar, Anal., 4, 224-234, 1974.
4. Kilgroe, J.D. and Licata, A., "Control of Air Pollution Emissions from Municipal Waste Combustors", Proceedings of the 17th Biennial Waste Processing Conference, ASME, NY, 1996.
5. Licata, M. Babu and L-P Nethe, "An Economic Alternative to Controlling Acid Gases, Mercury, and Dioxin from MWC's," Proceedings of the 87th Annual AWMA Meeting, Paper 94-MP-17.06, Cincinnati, Ohio, June 1994.
6. Midwest Research Institute. June 3, 1987. Results of the Combustion and Emissions Research Project at the Vicon Incinerator Facility in Pittsfield, MA - Volumes I & II. Prepared for NYSERDA.
7. Ogden Martin Systems, Inc. March 4, 1993. Volume I, Executive Summary, Environmental Test Report, Stanislaus County Resource Recovery Facility. Prepared for Ogden Martin Systems of Stanislaus, Inc., Crows Landing, CA.
8. Richman, D. Fickling and J. Hahn, "Mercury Removal Studies at a Municipal Waste Combustor in Marion County, Oregon," AWMA Municipal Waste Combustion Conference, Williamsburg, VA, March 1993.
9. Rigo, H. G., "How Good are Today's Mercury Test Methods and Controls?," Proceedings of the Ash 6 Management & Utilization Conference, Arlington, VA, November 16-17, 1993.
10. Rigo, H. G., "Selecting Statistically Meaningful Emission Rates," Air & Waste Management Association's 86th Annual Meeting & Exhibition, Denver, CO, June 13-18, 1993.
11. Rousseeuw, P. and Leroy, A., "Robust Regression and Outlier Detection", Wiley-Interscience, New Yorik, 1987.
12. Salvay Minerals, Private Communication to Jack Schmidt, DCERF, 1993.
13. Sierhuis and J.G.P. Born, "PCDD/F Emissions Related to the Operating Conditions of the Flue Gas Cleaning System of MWI-Amsterdam," Dioxin '94, Organohalogen Compounds, Volume 19, Kyoto, Japan, November 1994.
14. USEPA. September, 1993. Emission Test Report, Field Test of Carbon Injection for Mercury Control, Camden County Municipal Waste Combustor, Camden County, NJ. Air & Energy Engineering Research Lab. [OAQPS/EPA].

    Townsend, D.I., Wilson, J.D. and Park, C.N., "Mechanisms and Formation and Options for Control of Emissions of PCDD's/PCDF's from Incineration," International Incineration Conference Proceedings, May 8-12, 1995.

APPENDIX A

MEASURED EMISSIONS CHARACTERISTICS

The following data table is a summary of all the stack gas emissions test results. In addition to the Section 129 pollutants discussed in the body of this report, the rest of the metals readily analyzable using ICAP on the front and back half of the Method 29 train are provided. The Method 26 train was analyzed for HF and F. The Method 23 train was analyzed for a plethora of other organics that appear in risk assessments and public forums. It should be noted that the majority of these organics are BDL despite following the best available protocols as described in the Volume II Analytic Laboratory Reports.

Since the non-Section 129 results are produced following good practice, but using unvalidated methods, they should be used cautiously.

The variable names are all defined at the end of the data table.

Appendix A -- Measured emissions characteristics.

		TRONA		PAC		Ttrgt	O_2	CO_2	CO	SO_2-24 hr geo	NOx-24	THC	Opacity	Stack TEMP	Stack FLOW	PPMdv @ 7% O2 HF	Cl2	HCl		TSP	Cd	Pb	Hg	TOTDXN
							all @ 7% O_2													all at 7% O2				
DATE	TEST I.D.	lb/h	mg/dsm^3	lb/h	mg/dsm^3	°F	%	%	PPMdv	PPMdv	Eff	PPMdv	PPMdv	%	Deg F	DSm3/hr				Eff	mg/dsm3	µg/scm3	µg/scm3	µg/scm3	ng/dscm3
951117	T01	150	1,938	0	0	420	10.9	9.5	56	96	11%	269	2.0	2.4	417	48,810	3.1	0.8	340	27%	20.5	18	249	155	116
951117	T02(HCl)	150	1,980	0	0	420	10.9							2.4			3.0	0.7	341	27%					
951118	T02	150	2,065	0	0	420	11.1	9.1	70	41	62%	256	1.5	2.3	417	46,731	(2.6)	(0.4)	193	59%	9.4	12	293	92	91
951118	T03	150	2,008	0	0	420	10.8	9.4	83	43	60%	227	1.2	2.4	408	46,622	(2.5)	3.3	158	66%	12.4	14	485	247	87
951119	T04	150	1,994	27	359	420	11.0	9.3	62	62	43%	227	0.9	2.2	412	47,917	7.7	(0.4)	300	36%	5.5	16	163	60	37
951119	T05	150	1,960	27	353	420	10.9	9.2	69	49	55%	236	1.1	2.2	414	48,252	3.0	1.6	252	46%	6.9	17	170	43	15
191120	T06	0	0	0	0	420	10.3	9.6	42	131		242	0.7	1.7	408	45,283	2.5	(0.1)	542		6.7	16	168	145	115
951120	T07	0	0	0	0	420	10.4	9.7	52	85		236	0.6	1.8	389	43,249	3.3	3.0	394		2.9	9	82	69	98
951121	T08	150	2,011	27	361	350	10.3	10.0	48	41	62%	242	1.0	2.0	346	44,407	2.4	0.05	221	53%		4	60	20	20
951121	T09	149	2,090	27	374	350	10.7	9.4	70	37	66%	223	0.1	2.3	353	44,151	(2.4)	(0.03)	260	44%		6	141	24	17
951122	T10	151	2,041	27	365	300	11.0	9.3	70	46	57%	499	0.6	2.9	296	47,037	2.8	(0.04)	196	58%	2.6	11	100	1,037	154
951122	T11	150	1,989	31	416	300	10.7	9.5	63	34	69%	215	1.2	3.0	304	46,715	(2.4)	(0.03)	139	70%	6.3	12	103	22	6.0
951123	T12	151	1,995	0	0	300	10.7	9.6	63	53	51%	260	0.5	2.8	302	46,667	2.5	(0.04)	170	64%	2.5	7	115	*104*	151
951123	T13	150	2,033	0	0	300	11.1	9.0	61	56	48%	270	1.8	3.1	305	47,382	2.7	0.08	177	62%	0.9	9	102	258	127
951124	T14	150	1,920	27	345	350	10.7	9.4	78	42	61%	259	0.2	2.0	348	48,367	3.5	(0.04)	399	15%	0.2	7	126	22	7.4
951124	T15	150	1,925	27	347	350	10.5	9.5	58	51	53%	264	0.8	2.5	350	47,105	(2.4)	0.10	175	63%	5.0	9	110	22	3.4
951125	T16	150	1,902	20	251	350	10.6	9.5	84	53	51%	353	1.2	2.3	349	48,285	(2.4)	0.05	174	63%	1.3	7	112	20	5.3
951125	T17	150	2,057	19	261	350	10.7	9.5	70	48	56%	251	1.1	2.7	347	45,059	(2.5)	0.07	141	70%	5.8	133	183	25	4.5
95126	T18	150	1,939	0	0	350	10.0	10.1	60	48	56%	219	0.3	2.1	342	44,791	3.0	0.06	148	68%	4.6	6	104	89	83
95126	T19	150	2,050	0	0	350	10.4	9.7	249	34	69%	216	3.0	2.1	345	43,969	11.1	0.3	160	66%	4.0	8	220	202	250
951127	T20	149	1,967	19	253	300	10.3	9.7	50	46	57%	241	0.4	2.1	318	45,137	(2.4)	0.6	169	64%	2.0	58	80	22	12
951127	T21	150	1,964	20	259	300	10.5	9.5	234	25	77%	249	5.1	2.1	319	46,290	2.6	0.3	257	45%	7.6	90	111	17	11
951128	T22	150	2,204	27	397	325	10.9	9.2	62	36	67%	233	0.5	1.7	323	42,920	(2.5)	0.3	247	47%	30	262	146	17	3.0
951128	T23	150	1,975	27	356	325	10.0	10.1	56	52	52%	237	0.7	1.9	330	43,924					20	16	210	15	3.3

Appendix A -- Measured emissions characteristics.

		TRONA		PAC			all at 7% O2							all at 7% O2					all at 7% O2	
						Ttrgt	As	Sb	Se	Li	Al	Ba	Be	Ca	Cr	Co	Cu	Fe	Mg	Mn
DATE	TEST I.D.	lb/h	mg/dsm^3	lb/h	mg/dsm^3	°F	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3
951117	T01	150	1,938	0	0	420	2.4	53	14	0.6	134	134	(0.2)	249	3.0	(1.9)	46	108	43	5.9
951117	T02(HCl)	150	1,980	0	0	420														
951118	T02	150	2,065	0	0	420	59	22	4.8	0.5	100	6.6	(0.2)	200	3.6	(2.0)	39	87	39	4.8
951118	T03	150	2,008	0	0	420	16	19	3.5	0.5	93	6.4	(0.2)	186	2.4	(2.0)	34	49	17	9.3
951119	T04	150	1,994	27	359	420	2.9	16	(2.2)	0.5	85	5.4	(0.2)	163	2.3	(2.0)	25	48	20	3.0
951119	T05	150	1,960	27	353	420	2.5	33	3.6	0.7	91	7.2	(0.2)	176	2.5	(2.0)	27	59	39	4.4
191120	T06	0	0	0	0	420	(2.1)	14	(2.1)	0.3	265	5.4	(0.2)	336	7.1	(1.9)	35	129	30	4.4
951120	T07	0	0	0	0	420	5.2	18	6.3	(0.2)	76	3.1	(0.2)	126	1.9	(1.9)	13	44	(9)	1.8
951121	T08	150	2,011	27	361	350	(2.1)	6	4.4	(0.2)	78	3.0	(0.2)	143	2.2	(1.9)	16	273	16	8.4
951121	T09	149	2,090	27	374	350	(2.1)	10	3.0	(0.2)	83	4.0	(0.2)	282	1.2	(1.9)	19	48	21	1.7
951122	T10	151	2,041	27	365	300	(2.4)	11	(2.4)	(0.2)	71	3.1	(0.2)	235	1.5	(2.1)	19	250	(11)	4.1
951122	T11	150	1,989	31	416	300	(2.3)	11	2.4	(0.2)	58	4.9	(0.2)	130	2.0	(2.1)	19	45	11	2.2
951123	T12	151	1,995	0	0	300	(2.2)	6	(2.2)	(0.2)	68	3.2	(0.2)	129	1.6	(2.0)	14	41	13	2.1
951123	T13	150	2,033	0	0	300	(2.2)	8	3.4	(0.2)	59	3.5	(0.2)	129	4.9	(2.0)	17	37	35	4.7
951124	T14	150	1,920	27	345	350	(2.2)	13	(2.2)	0.3	86	4.2	(0.2)	252	1.6	(2.0)	16	64	37	3.4
951124	T15	150	1,925	27	347	350	3.2	10	3.4	*0.7*	*(61)*	*(0.2)*	(0.2)	*(41)*	*2.0*	(2.0)	22	*81*	*272*	*15.6*
951125	T16	150	1,902	20	251	350	(2.2)	9	(2.2)	0.4	66	3.3	(0.2)	210	2.8	(2.0)	11	72	42	6.2
951125	T17	150	2,057	19	261	350	(2.3)	7	12	0.3	84	5.3	(0.2)	232	2.0	(2.1)	13	67	22	154.4
95126	T18	150	1,939	0	0	350	(2.3)	6	(2.3)	0.3	97	4.5	(0.2)	221	2.5	(2.1)	17	56	37	4.1
95126	T19	150	2,050	0	0	350	(2.4)	11	(2.4)	(0.2)	102	4.5	(0.2)	293	3.0	(2.2)	22	69	45	3.5
951127	T20	149	1,967	19	253	300	(2.2)	8	2.8	0.2	61	4.0	(0.2)	146	1.9	(2.0)	20	53	24	25.9
951127	T21	150	1,964	20	259	300	(2.3)	13	4.9	(0.2)	83	5.3	(0.2)	160	76	(2.1)	28	194	38	11.8
951128	T22	150	2,204	27	397	325	(2.4)	7	4.2	(0.2)	124	7.3	(0.2)	241	39	3.0	31	233	47	8.7
951128	T23	150	1,975	27	356	325	2.8	5	(2.2)	(0.2)	102	5.7	(0.2)	203	62	2.4	24	292	40	9.5

Appendix A -- Measured emissions characteristics.

		TRONA		PAC		Ttrgt	Mo	Ni	P	K	Ag	Na	St	Tl	V	Zn	B	Si	Sn	Ti
							all at 7% O2							all at 7% O2						all at 7% O
DATE	TEST I.D.	lb/h	mg/dsm³	lb/h	mg/dsm³	°F	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3	µg/scm3
951117	T01	150	1,938	0	0	420	12	3.0	33.2	2168.7	(1.9)	2,743	1.3	(11.5)	(1.0)	957	421.0	95,679	185	5.5
951117	T02(HCl)	150	1,980	0	0	420														
951118	T02	150	2,065	0	0	420	8.0	5.0	(12)	1,996	(2.0)	2,662	1.1	(12.0)	(1.0)	799	240	106,473	19	(4.0)
951118	T03	150	2,008	0	0	420	9.3	3.0	23	2,592	(2.0)	2,858	1.3	(12.0)	(1.0)	864	226	99,684	28	(4.0)
951119	T04	150	1,994	27	359	420	8.5	5.3	(12)	1,631	(2.0)	2,153	1.0	(11.7)	(1.0)	594	241	97,880	18	(3.9)
951119	T05	150	1,960	27	353	420	8.5	4.6	16	1,828	(2.0)	2,415	1.0	(11.7)	(1.0)	783	385	104,430	20	(3.9)
191120	T06	0	0	0	0	420	10	7.1	(12)	1,228	(1.9)	2,262	1.7	(11.6)	(1.0)	711	284	109,870	25	4.8
951120	T07	0	0	0	0	420	8.2	3.5	(11)	692	(1.9)	1,448	0.6	(11.3)	(0.9)	296	384	106,992	10	(3.8)
951121	T08	150	2,011	27	361	350	8.4	3.8	(12)	487	(1.9)	1,299	0.5	(11.7)	(1.0)	214	260	97,450	(10)	(3.9)
951121	T09	149	2,090	27	374	350	10	(1.9)	(12)	898	(1.9)	1,925	0.8	(11.6)	(1.0)	289	167	96,262	17	(3.9)
951122	T10	151	2,041	27	365	300	8.6	4.4	(13)	785	(2.1)	1,926	1.4	(12.8)	(1.1)	713	478	121,253	16	(4.3)
951122	T11	150	1,989	31	416	300	8.2	5.9	(12)	960	(2.1)	1,577	0.6	(12.3)	(1.0)	364	89	109,739	23	(4.1)
951123	T12	151	1,995	0	0	300	10	(2.0)	(12)	643	(2.0)	1,488	1.0	(12.2)	(1.0)	379	325	121,763	32	(4.1)
951123	T13	150	2,033	0	0	300	7.5	6.6	(12)	881	(2.0)	1,559	1.0	(12.2)	(1.0)	352	325	108,445	18	(4.1)
951124	T14	150	1,920	27	345	350	8.0	4.6	(12)	796	(2.0)	2,853	1.8	(11.9)	(1.0)	212	365	106,157	21	(4.0)
951124	T15	150	1,925	27	347	350	(2.0)	7.5	62	1,222	(2.0)	3,871	(0.2)	(12.2)	(1.0)	503	(2)	63,153	26	203.7
951125	T16	150	1,902	20	251	350	7.2	2.5	(12)	788	(2.0)	2,496	1.2	(11.8)	(1.0)	250	315	118,232	20	(3.9)
951125	T17	150	2,057	19	261	350	7.7	4.1	(13)	772	(2.1)	2,176	0.9	(12.6)	(1.1)	519	154	126,364	18	(4.2)
95126	T18	150	1,939	0	0	350	5.8	3.0	(12)	761	(2.1)	2,144	1.4	(12.4)	(1.0)	609	221	124,485	17	(4.1)
95126	T19	150	2,050	0	0	350	8.1	3.1	(13)	805	2.7	2,122	1.2	(13.2)	(1.1)	520	417	131,741	25	(4.4)
951127	T20	149	1,967	19	253	300	5.6	2.1	(12)	731	(2.0)	1,595	0.8	(12.0)	(1.0)	253	266	66,476	27	(4.0)
951127	T21	150	1,964	20	259	300	19	28	(12)	833	(2.1)	2,292	0.8	(12.5)	(1.0)	368	382	97,220	19	(4.2)
951128	T22	150	2,204	27	397	325	17	31	15	1,093	(2.2)	2,333	1.4	(13.1)	(1.1)	532	576	131,217	30	4.6
951128	T23	150	1,975	27	356	325	18	52	(12)	814	(2.0)	2,509	2.1	(12.2)	(1.0)	210	508	108,479	20	(4.1)

Appendix A -- Measured emissions characteristics.

		TRONA		PAC			all at 7% O2								all at 7% O2					
DATE	TEST I.D.	lb/h	mg/dsm^3	lb/h	mg/dsm^3	Ttrgt °F	DCB2 ng/dsm3	DCB3 ng/dsm3	DCB4 ng/dsm3	TRICB23 ng/dsm3	TRICB24 ng/dsm3	TRICB35 ng/dsm3	TCB234 ng/dsm3	TCB235 ng/dsm3	PECB ng/dsm3	HXCB ng/dsm3	DCP23 ng/dsm3	DCP24 ng/dsm3	DCP25 ng/dsm3	DCP26 ng/dsm3
951117	T01	150	1,938	0	0	420	351	414	437	422	1,405	164	507	1,093	773	226	(156)	(742)	(742)	(156)
951117	T02(HCl)	150	1,980	0	0	420														
951118	T02	150	2,065	0	0	420	434	552	868	529	1,736	221	789	1,420	1,105	355	(158)	(544)	(544)	(158)
951118	T03	150	2,008	0	0	420	403	532	468	492	1,371	202	629	1,210	887	307	(161)	(428)	(428)	(161)
951119	T04	150	1,994	27	359	420	148	173	247	181	469	(165)	222	436	378	(165)	(165)	(403)	(403)	(165)
951119	T05	150	1,960	27	353	420	466	589	638	401	1,227	180	417	785	515	(164)	(164)	(393)	(393)	(164)
191120	T06	0	0	0	0	420	609	665	1,042	537	2,244	208	673	1,442	1,362	288	(160)	(288)	(288)	(160)
951120	T07	0	0	0	0	420	602	700	1,058	553	1,953	212	643	1,384	1,139	301	(163)	(383)	(383)	(163)
951121	T08	150	2,011	27	361	350	378	436	987	206	609	(164)	(164)	362	(164)	(164)	(164)	(164)	(164)	(164)
951121	T09	149	2,090	27	374	350	416	522	898	286	816	(163)	212	530	204	(163)	(163)	(163)	(163)	(163)
951122	T10	151	2,041	27	365	300	666	801	1,603	810	2,024	321	928	2,024	1,434	523	(169)	(523)	(523)	(169)
951122	T11	150	1,989	31	416	300	333	406	698	187	560	(162)	(162)	300	(162)	(162)	(162)	(162)	(162)	(162)
951123	T12	151	1,995	0	0	300	586	673	950	578	1,188	238	697	1,505	871	253	(158)	(451)	(451)	(158)
951123	T13	150	2,033	0	0	300	561	640	1,342	600	1,421	229	726	1,500	947	340	(158)	(371)	(371)	(158)
951124	T14	150	1,920	27	345	350	650	738	952	293	873	159	167	460	(159)	(159)	(159)	(159)	(159)	(159)
951124	T15	150	1,925	27	347	350	592	695	1,974	284	1,026	(158)	(158)	403	(158)	(158)	(158)	(174)	(174)	(158)
951125	T16	150	1,902	20	251	350	718	780	2,028	382	1,014	179	265	624	265	(156)	(156)	(936)	(936)	(156)
951125	T17	150	2,057	19	261	350	590	721	983	352	1,065	164	270	647	246	(164)	(164)	(180)	(180)	(164)
95126	T18	150	1,939	0	0	350	676	896	1,059	521	1,711	228	570	1,303	635	204	(163)	(521)	(521)	(163)
95126	T19	150	2,050	0	0	350	1,196	1,025	1,196	940	2,990	333	1,367	2,734	1,879	487	(171)	(572)	(572)	(171)
951127	T20	149	1,967	19	253	300	940	862	1,019	431	1,489	212	306	737	266	(157)	(157)	(157)	(157)	(157)
951127	T21	150	1,964	20	259	300	1,405	909	909	719	1,736	240	422	826	388	(165)	(165)	(1,322)	(1,322)	(165)
951128	T22	150	2,204	27	397	325	741	802	1,121	284	810	(1,724)	(172)	379	(172)	(172)	(172)	(172)	(172)	(172)
951128	T23	150	1,975	27	356	325	680	801	881	296	881	(160)	(160)	424	(160)	(160)	(160)	(160)	(160)	(160)

Appendix A -- Measured emissions characteristics.

		TRONA		PAC			ll at 7% O2					all at 7% O2					all at 7% O2		
DATE	TEST I.D.	lb/h	mg/dsm^3	lb/h	mg/dsm^3	Ttrgt °F	DCP34 ng/dsm3	DCP35 ng/dsm3	TRICP234 ng/dsm3	TRICP235 ng/dsm3	TRICP236 ng/dsm3	TRICP245 ng/dsm3	TRICP246 ng/dsm3	TRICP345 ng/dsm3	TCP2345 ng/dsm3	TCP2346 ng/dsm3	TCP2356 ng/dsm3	PECP ng/dsm3	MONOCBP ng/dsm3	DICBP ng/dsm3
951117	T01	150	1,938	0	0	420	(156)	(156)	203	(156)	(156)	242	2,342	(156)	(156)	1,951	2,420	539	(11)	(23)
951117	T02(HCl)	150	1,980	0	0	420														
951118	T02	150	2,065	0	0	420	(158)	(158)	166	(158)	(158)	205	3,708	(158)	(158)	2,998	(158)	1,026	(11)	(14)
951118	T03	150	2,008	0	0	420	(161)	(161)	(161)	(161)	(161)	(161)	2,178	(161)	(161)	1,775	(161)	613	(12)	(15)
951119	T04	150	1,994	27	359	420	(165)	(165)	(165)	(165)	(165)	(165)	1,892	(165)	(165)	1,316	(165)	370	(14)	(17)
951119	T05	150	1,960	27	353	420	(164)	(164)	(164)	(164)	(164)	(164)	2,373	(164)	(164)	818	(164)	221	(12)	(12)
191120	T06	0	0	0	0	420	(160)	(160)	(160)	(160)	(160)	(160)	1,843	(160)	(160)	1,683	(160)	697	(6)	(7)
951120	T07	0	0	0	0	420	(163)	(163)	(163)	(163)	(163)	(163)	2,035	(163)	(163)	1,465	(163)	570	(9)	(8)
951121	T08	150	2,011	27	361	350	(164)	(164)	(164)	(164)	(164)	(164)	387	(164)	(164)	(164)	(164)	(164)	(16)	(9)
951121	T09	149	2,090	27	374	350	(163)	(163)	(163)	(163)	(163)	(163)	530	(163)	(163)	220	(163)	(163)	(13)	(10)
951122	T10	151	2,041	27	365	300	(169)	(169)	194	(169)	(169)	270	1,265	(169)	194	1,350	(169)	607	(16)	(236)
951122	T11	150	1,989	31	416	300	(162)	(162)	(162)	(162)	(162)	(162)	(317)	(162)	(162)	(162)	(162)	(162)	(24)	(60)
951123	T12	151	1,995	0	0	300	(158)	(158)	(158)	(158)	(158)	158	1,188	(158)	(158)	950	(158)	341	(21)	(43)
951123	T13	150	2,033	0	0	300	(158)	(158)	(158)	(158)	(158)	(158)	1,105	(158)	(158)	869	(158)	324	(15)	(30)
951124	T14	150	1,920	27	345	350	(159)	(159)	(159)	(159)	(159)	(159)	563	(159)	(159)	175	(159)	(159)	(10)	(53)
951124	T15	150	1,925	27	347	350	(158)	(158)	(158)	(158)	(158)	(158)	553	(158)	(158)	174	(158)	(158)	(7)	(18)
951125	T16	150	1,902	20	251	350	(156)	(156)	(156)	(156)	(156)	(156)	1,872	(156)	(156)	374	(156)	(156)	(9)	(23)
951125	T17	150	2,057	19	261	350	(164)	(164)	(164)	(164)	(164)	(164)	377	(164)	(164)	262	(164)	(164)	(15)	(39)
95126	T18	150	1,939	0	0	350	(163)	(163)	(163)	(163)	(163)	171	1,711	(163)	(163)	1,222	(163)	440	(12)	(29)
95126	T19	150	2,050	0	0	350	(171)	(171)	239	(171)	(171)	308	1,965	(171)	231	1,794	(171)	940	(15)	(13)
951127	T20	149	1,967	19	253	300	(157)	(157)	(157)	(157)	(157)	(157)	(157)	(157)	(157)	243	(157)	(157)	(14)	(8)
951127	T21	150	1,964	20	259	300	(165)	(165)	(165)	(165)	(165)	(165)	3,141	(165)	(165)	355	(165)	(165)	(14)	(12)
951128	T22	150	2,204	27	397	325	(172)	(172)	(172)	(172)	(172)	(172)	552	(172)	(172)	(172)	(172)	(172)	(11)	(11)
951128	T23	150	1,975	27	356	325	(160)	(160)	(160)	(160)	(160)	(160)	224	(160)	(160)	(160)	(160)	(160)	(14)	(9)

Appendix A -- Measured emissions characteristics.

		TRONA		PAC			all at 7% O2						all at 7% O2					all at 7% O2		
DATE	TEST I.D.	lb/h	mg/dsm^3	lb/h	mg/dsm^3	Ttrgt °F	TRICBP ng/dsm3	TCBP ng/dsm3	PECBP ng/dsm3	HXCBP ng/dsm3	HPCBP ng/dsm3	OCBP ng/dsm3	NONACBP ng/dsm3	DECBP ng/dsm3	PCBS ng/dsm3	NAPHLENE ng/dsm3	ACENPHLN ng/dsm3	ACENATHN ng/dsm3	FLUORENE ng/dsm3	PHENATHN ng/dsm3
951117	T01	150	1,938	0	0	420	(17)	(23)	(12)	(8)	(8)	(20)	(22)	(34)	(34)	2,732	(78)	(78)	(78)	148
951117	T02(HCl)	150	1,980	0	0	420														
951118	T02	150	2,065	0	0	420	(15)	(15)	(7)	(15)	(17)	(17)	(23)	(17)	(32)	2,762	(79)	(79)	(79)	95
951118	T03	150	2,008	0	0	420	(16)	(8)	(19)	(10)	(9)	(29)	(23)	(34)	(34)	2,823	(81)	(81)	(81)	(81)
951119	T04	150	1,994	27	359	420	(18)	(16)	(22)	(11)	(18)	(30)	(25)	(37)	(37)	3,209	(82)	(99)	(82)	(82)
951119	T05	150	1,960	27	353	420	(19)	(15)	(20)	(10)	(16)	(30)	(25)	(36)	(36)	5,073	(82)	(82)	(82)	(82)
191120	T06	0	0	0	0	420	(7)	(6)	(26)	(6)	(7)	(10)	(6)	(7)	(27)	2,244	(80)	(80)	(80)	(80)
951120	T07	0	0	0	0	420	(18)	(5)	(35)	(11)	(10)	(7)	(6)	(7)	(35)	1,790	(81)	(81)	(81)	(81)
951121	T08	150	2,011	27	361	350	(13)	(10)	(12)	(12)	(8)	(7)	(11)	(10)	(13)	1,645	(82)	(82)	(82)	123
951121	T09	149	2,090	27	374	350	(49)	(7)	(10)	(10)	(8)	(11)	(8)	(7)	(49)	2,203	(82)	(82)	(82)	163
951122	T10	151	2,041	27	365	300	(143)	(19)	(253)	(15)	(4)	(6)	(19)	(8)	(253)	2,109	(84)	(84)	(84)	169
951122	T11	150	1,989	31	416	300	(114)	(17)	(219)	(16)	(5)	(11)	(10)	(8)	(219)	893	(81)	(81)	(81)	(81)
951123	T12	151	1,995	0	0	300	(59)	(14)	(158)	(11)	(12)	(9)	(10)	(10)	(158)	2,535	(79)	(79)	(79)	95
951123	T13	150	2,033	0	0	300	(53)	(9)	(95)	(9)	(5)	(4)	(6)	(7)	(95)	3,079	(79)	(79)	(79)	(79)
951124	T14	150	1,920	27	345	350	(151)	(24)	(412)	(20)	(10)	(8)	(7)	(9)	(412)	1,745	(79)	(79)	(79)	(79)
951124	T15	150	1,925	27	347	350	(39)	(13)	(9)	(13)	(6)	(7)	(6)	(8)	(39)	1,737	(79)	(79)	(79)	(79)
951125	T16	150	1,902	20	251	350	(78)	(15)	(218)	(9)	(9)	(6)	(6)	(9)	(218)	15,598	1,248	(78)	(78)	647
951125	T17	150	2,057	19	261	350	(66)	(11)	(172)	(13)	(8)	(8)	(7)	(9)	(172)	1,475	(82)	(82)	(82)	(82)
95126	T18	150	1,939	0	0	350	(46)	(7)	(90)	(7)	(9)	(8)	(7)	(10)	(90)	1,548	(81)	(81)	(81)	114
95126	T19	150	2,050	0	0	350	(36)	(10)	(80)	(12)	(10)	(9)	(8)	(10)	(80)	1,965	(85)	(85)	(85)	94
951127	T20	149	1,967	19	253	300	(9)	(6)	(16)	(7)	(8)	(8)	(6)	(9)	(16)	2,038	(78)	(78)	(78)	(78)
951127	T21	150	1,964	20	259	300	(7)	(6)	(16)	(8)	(15)	(7)	(7)	(8)	(16)	9,091	99	(83)	(83)	430
951128	T22	150	2,204	27	397	325	(8)	(8)	(11)	(9)	(8)	(8)	(7)	(9)	(11)	1,810	(86)	(86)	(86)	(86)
951128	T23	150	1,975	27	356	325	(15)	(8)	(10)	(6)	(6)	(7)	(6)	(7)	(15)	1,681	(80)	(80)	264	(80)

Appendix A -- Measured emissions characteristics.

		TRONA		PAC						all at 7% O2					all at 7% O2					all at 7% O
DATE	TEST I.D.	lb/h	mg/dsm^3	lb/h	mg/dsm^3	Ttrgt °F	ANTRACNE ng/dsm3	FLUANTHN ng/dsm3	PYRENE ng/dsm3	BENZANTH ng/dsm3	CHRYSENE ng/dsm3	BNZBFLAN ng/dsm3	BNZKFLAN ng/dsm3	BENAPYRN ng/dsm3	INDEPYRN ng/dsm3	DIBNZANT ng/dsm3	BNZPERLN ng/dsm3	TETRALIN ng/dsm3	QUINOLN ng/dsm3	MTLNAPH2 ng/dsm3
951117	T01	150	1,938	0	0	420	(78)	(101)	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(1,171)	(234)	(156)
951117	T02(HCl)	150	1,980	0	0	420														
951118	T02	150	2,065	0	0	420	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	1,026	(237)	(158)
951118	T03	150	2,008	0	0	420	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	1,129	(242)	(161)
951119	T04	150	1,994	27	359	420	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	1,234	(247)	(165)
951119	T05	150	1,960	27	353	420	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	1,473	(245)	(164)
191120	T06	0	0	0	0	420	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(1,042)	(240)	(160)
951120	T07	0	0	0	0	420	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(1,058)	(244)	(163)
951121	T08	150	2,011	27	361	350	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	773	(247)	(164)
951121	T09	149	2,090	27	374	350	(82)	131	114	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	898	(245)	(163)
951122	T10	151	2,041	27	365	300	(84)	160	(84)	(84)	(84)	(84)	(84)	(84)	(84)	(84)	(84)	843	(253)	(169)
951122	T11	150	1,989	31	416	300	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	373	(244)	(162)
951123	T12	151	1,995	0	0	300	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	1,109	(238)	(158)
951123	T13	150	2,033	0	0	300	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	1,342	(237)	(158)
951124	T14	150	1,920	27	345	350	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(873)	(238)	(159)
951124	T15	150	1,925	27	347	350	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(79)	(869)	(237)	(158)
951125	T16	150	1,902	20	251	350	(78)	296	320	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(936)	(234)	(156)
951125	T17	150	2,057	19	261	350	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(82)	(787)	(246)	(164)
95126	T18	150	1,939	0	0	350	(81)	130	90	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(81)	(521)	(244)	(163)
95126	T19	150	2,050	0	0	350	(85)	(85)	(85)	(85)	(85)	(85)	(85)	(85)	(85)	(85)	(85)	701	(256)	(171)
951127	T20	149	1,967	19	253	300	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(78)	(1,332)	(235)	(157)
951127	T21	150	1,964	20	259	300	(83)	(83)	(83)	(83)	(83)	(83)	(83)	(83)	(83)	(83)	(83)	(992)	(248)	281
951128	T22	150	2,204	27	397	325	(86)	(86)	(86)	(86)	(86)	(86)	(86)	(86)	(86)	(86)	(86)	(862)	(259)	(172)
951128	T23	150	1,975	27	356	325	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(1,041)	(240)	(160)

Appendix A -- Measured emissions characteristics.

		TRONA		PAC		Ttrgt	MTLNAPH1	BIPHNYL	CHLNAP2	BNZAFLNE	BNZBFLNE	TERPHNLM	TERPHNLO	TERPHNLP	MTHANCE2	MTHPHN1	MTHPHN9	DIMTHAN	BENZBNTH	TRIPHLNE
							all at 7% O2								all at 7% O2					all at 7% O2
DATE	TEST I.D.	lb/h	mg/dsm^3	lb/h	mg/dsm^3	°F	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3
951117	T01	150	1,938	0	0	420	(156)	289	(156)	(156)	(156)	(156)	(156)	(156)	(156)	(156)	(156)	(624)	(156)	(156)
951117	T02(HCl)	150	1,980	0	0	420														
951118	T02	150	2,065	0	0	420	(158)	450	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(631)	(158)	(158)
951118	T03	150	2,008	0	0	420	(161)	468	(161)	(161)	(161)	(161)	(161)	(161)	(161)	(161)	(161)	(645)	(161)	(161)
951119	T04	150	1,994	27	359	420	(165)	494	(165)	(165)	(165)	(165)	(165)	(165)	(165)	(165)	(165)	(658)	(165)	(165)
951119	T05	150	1,960	27	353	420	(164)	1,718	(164)	(164)	(164)	(164)	(164)	(164)	(164)	(164)	(164)	(655)	(164)	(164)
191120	T06	0	0	0	0	420	(160)	881	(160)	(160)	(160)	(160)	(160)	(160)	(160)	(160)	(160)	(641)	(160)	(160)
951120	T07	0	0	0	0	420	(163)	1,058	(163)	(163)	(163)	(163)	(163)	(163)	(163)	(163)	(163)	(651)	(163)	(163)
951121	T08	150	2,011	27	361	350	(164)	1,151	(164)	(164)	(164)	(164)	(164)	(164)	(164)	(164)	(164)	(658)	(164)	(164)
951121	T09	149	2,090	27	374	350	(163)	898	(163)	(163)	(163)	(163)	(163)	(163)	(163)	(163)	(163)	(653)	(163)	(163)
951122	T10	151	2,041	27	365	300	(169)	13,496	(169)	(169)	(169)	(169)	(169)	(169)	(169)	(169)	(169)	(675)	(169)	(169)
951122	T11	150	1,989	31	416	300	(162)	4,790	(162)	(162)	(162)	(162)	(162)	(162)	(162)	(162)	(162)	(649)	(162)	(162)
951123	T12	151	1,995	0	0	300	(158)	4,356	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(634)	(158)	(158)
951123	T13	150	2,033	0	0	300	(158)	3,474	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(632)	(158)	(158)
951124	T14	150	1,920	27	345	350	(159)	3,966	(159)	(159)	(159)	(159)	(159)	(159)	(159)	(159)	(159)	(635)	(159)	(159)
951124	T15	150	1,925	27	347	350	(158)	2,606	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(158)	(632)	(158)	(158)
951125	T16	150	1,902	20	251	350	(156)	2,418	(156)	(156)	(156)	(156)	(156)	(156)	(156)	(156)	(156)	(624)	(156)	(156)
951125	T17	150	2,057	19	261	350	(164)	1,475	(164)	(164)	(164)	(164)	(164)	(164)	(164)	(164)	(164)	(656)	(164)	(164)
95126	T18	150	1,939	0	0	350	(163)	1,466	(163)	(163)	(163)	(163)	(163)	(163)	(163)	(163)	(163)	(652)	(163)	(163)
95126	T19	150	2,050	0	0	350	(171)	940	(171)	(171)	(171)	(171)	(171)	(171)	(171)	(171)	(171)	(683)	(171)	(171)
951127	T20	149	1,967	19	253	300	(157)	400	(157)	(157)	(157)	(157)	(157)	(157)	(157)	(157)	(157)	(627)	(157)	(157)
951127	T21	150	1,964	20	259	300	273	992	(165)	(165)	(165)	(165)	(165)	(165)	(165)	(165)	(165)	(661)	(165)	(165)
951128	T22	150	2,204	27	397	325	(172)	440	(172)	(172)	(172)	(172)	(172)	(172)	(172)	(172)	(172)	(690)	(172)	(172)
951128	T23	150	1,975	27	356	325	(160)	512	(160)	(160)	(160)	(160)	(160)	(160)	(160)	(160)	(160)	(640)	(160)	(160)

Appendix A -- Measured emissions characteristics.

		TRONA		PAC			all at 7% O2					all at 7% O2					all at 7% O2			
						Ttrgt	BNZEPYRN	PERYLENE	DIMBZAN	MTHCLAN	PICENE	CORONENE	DIBZPYRN	TCDF2378	TCDD2378	PCDF1	PCDF4	PCDD1	HXCDF14	HXCDF16
DATE	TEST I.D.	lb/h	mg/dsm^3	lb/h	mg/dsm^3	°F	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3	ng/dsm3
951117	T01	150	1,938	0	0	420	(156)	(156)	(156)	(3,122)	(156)	(156)	(312)	3.67	0.42	1.72	1.95	0.74	2.26	1.01
951117	T02(HCl)	150	1,980	0	0	420														
951118	T02	150	2,065	0	0	420	(158)	(158)	(158)	(3,156)	(158)	(158)	(316)	3.63	0.32	1.42	1.42	0.43	1.58	0.72
951118	T03	150	2,008	0	0	420	(161)	(161)	(161)	(3,227)	(161)	(161)	(323)	2.98	0.27	1.45	1.45	0.43	1.86	0.89
951119	T04	150	1,994	27	359	420	(165)	(165)	(165)	(3,291)	(165)	(165)	(329)	1.07	0.10	0.56	0.60	0.21	0.91	0.39
951119	T05	150	1,960	27	353	420	(164)	(164)	(164)	(3,273)	(164)	(164)	(327)	0.38	0.04	0.15	0.22	0.06	0.31	0.14
191120	T06	0	0	0	0	420	(160)	(160)	(160)	(3,205)	(160)	(160)	(321)	4.25	0.32	2.08	2.16	0.75	2.56	1.44
951120	T07	0	0	0	0	420	(163)	(163)	(163)	(3,255)	(163)	(163)	(326)	3.66	0.28	1.87	1.55	0.60	2.03	1.22
951121	T08	150	2,011	27	361	350	(164)	(164)	(164)	(3,290)	(164)	(164)	(329)	0.22	0.02	0.09	0.14	0.06	0.24	0.12
951121	T09	149	2,090	27	374	350	(163)	(163)	(163)	(3,264)	(163)	(163)	(326)	0.27	0.02	0.11	0.15	0.05	0.26	0.13
951122	T10	151	2,041	27	365	300	(169)	(169)	(169)	(3,374)	(169)	(169)	(337)	5.57	0.47	3.46	2.95	1.01	3.54	2.02
951122	T11	150	1,989	31	416	300	(162)	(162)	(162)	(3,247)	(162)	(162)	(325)	0.10	0.03	0.08	0.08	0.04	0.11	0.07
951123	T12	151	1,995	0	0	300	(158)	(158)	(158)	(3,168)	(158)	(158)	(317)	5.86	0.50	3.25	2.85	0.95	3.17	1.82
951123	T13	150	2,033	0	0	300	(158)	(158)	(158)	(3,158)	(158)	(158)	(316)	4.42	0.39	2.29	2.45	0.87	2.76	1.42
951124	T14	150	1,920	27	345	350	(159)	(159)	(159)	(3,173)	(159)	(159)	(317)	0.17	0.02	0.10	0.11	0.04	0.15	0.09
951124	T15	150	1,925	27	347	350	(158)	(158)	(158)	(3,158)	(158)	(158)	(316)	0.07	0.01	0.03	0.04	0.02	0.06	0.04
951125	T16	150	1,902	20	251	350	(156)	(156)	(156)	(3,120)	(156)	(156)	(312)	0.12	0.02	0.05	0.06	0.02	0.09	0.05
951125	T17	150	2,057	19	261	350	(164)	(164)	(164)	(3,278)	(164)	(164)	(328)	0.12	0.02	0.05	0.06	0.02	0.07	0.04
95126	T18	150	1,939	0	0	350	(163)	(163)	(163)	(3,259)	(163)	(163)	(326)	3.50	0.27	1.63	1.55	0.46	1.63	0.81
95126	T19	150	2,050	0	0	350	(171)	(171)	(171)	(3,417)	(171)	(171)	(342)	9.40	0.72	4.36	4.02	1.71	6.24	3.33
951127	T20	149	1,967	19	253	300	(157)	(157)	(157)	(3,135)	(157)	(157)	(313)	0.38	0.04	0.20	0.23	0.09	0.31	0.16
951127	T21	150	1,964	20	259	300	(165)	(165)	(165)	(3,306)	(165)	(165)	(331)	0.31	0.02	(0.11)	0.14	0.06	0.20	0.10
951128	T22	150	2,204	27	397	325	(172)	(172)	(172)	(3,448)	(172)	(172)	(345)	0.07	0.01	0.04	0.05	0.02	0.07	0.04
951128	T23	150	1,975	27	356	325	(160)	(160)	(160)	(3,202)	(160)	(160)	(320)	0.06	0.01	0.03	0.04	0.02	0.07	0.04

Appendix A -- Measured emissions characteristics.

		TRONA		PAC			all at 7% O2					all at 7% O2						all at 7% O2		
DATE	TEST I.D.	lb/h	mg/dsm^3	lb/h	mg/dsm^3	Ttrgt °F	HXCDF46 ng/dsm3	HXCDF19 ng/dsm3	HXCDD14 ng/dsm3	HXCDD16 ng/dsm3	HXCDD19 ng/dsm3	HPCDF146 ng/dsm3	HPCDF149 ng/dsm3	HPCDD146 ng/dsm3	OCDF ng/dsm3	OCDD ng/dsm3	TCDF ng/dsm3	PCDF ng/dsm3	HXCDF ng/dsm3	HPCDF ng/dsm3
951117	T01	150	1,938	0	0	420	1.09	(0.08)	0.47	0.70	1.01	3.36	0.27	5.00	0.47	7.81	31.22	25.76	10.15	5.31
951117	T02(HCl)	150	1,980	0	0	420														
951118	T02	150	2,065	0	0	420	0.74	(0.06)	0.24	0.36	0.50	2.05	0.18	2.45	0.31	4.02	35.51	21.30	7.02	3.24
951118	T03	150	2,008	0	0	420	0.97	(0.10)	0.23	0.39	0.55	2.50	0.31	2.74	0.52	4.76	27.43	21.78	8.87	4.28
951119	T04	150	1,994	27	359	420	0.46	(0.05)	0.14	0.21	0.31	1.32	0.16	1.65	0.31	3.21	9.05	8.23	4.03	2.22
951119	T05	150	1,960	27	353	420	0.20	(0.04)	0.06	0.12	0.15	0.52	0.08	0.98	0.17	1.96	2.95	2.54	1.47	0.90
191120	T06	0	0	0	0	420	1.28	0.11	0.48	0.62	0.88	3.61	0.39	3.21	0.71	5.29	37.66	30.45	12.82	5.85
951120	T07	0	0	0	0	420	1.06	0.11	0.33	0.55	0.72	3.01	0.33	3.09	0.67	5.37	31.74	24.41	10.58	4.88
951121	T08	150	2,011	27	361	350	0.18	0.04	0.11	0.27	0.30	0.43	0.06	2.30	0.12	4.52	1.40	1.64	1.15	0.59
951121	T09	149	2,090	27	374	350	0.21	0.04	0.10	0.19	0.23	0.51	0.08	1.71	0.29	3.59	1.71	1.96	1.31	0.90
951122	T10	151	2,041	27	365	300	1.52	0.15	0.59	0.59	1.01	3.88	0.32	2.70	0.57	4.22	53.98	44.70	17.71	5.90
951122	T11	150	1,989	31	416	300	0.07	0.03	0.06	0.07	0.10	0.21	0.06	0.42	0.23	1.06	0.80	0.89	0.60	0.41
951123	T12	151	1,995	0	0	300	1.58	0.13	0.54	0.58	1.03	3.49	0.23	3.01	0.44	5.07	50.69	43.56	15.84	5.07
951123	T13	150	2,033	0	0	300	1.50	0.14	0.58	0.66	1.11	3.87	0.32	3.95	0.71	7.42	37.11	32.37	13.42	6.00
951124	T14	150	1,920	27	345	350	0.10	(0.03)	0.05	0.07	0.09	0.26	0.04	0.59	0.09	1.19	1.19	1.27	0.71	0.37
951124	T15	150	1,925	27	347	350	0.05	0.03	0.03	0.04	0.04	0.13	0.02	0.28	0.12	0.64	0.40	0.44	0.32	0.23
951125	T16	150	1,902	20	251	350	0.05	0.02	0.37	0.06	0.06	0.15	0.02	0.38	0.06	0.78	1.09	0.78	0.44	0.21
951125	T17	150	2,057	19	261	350	0.04	0.03	0.03	0.04	0.05	0.11	0.02	0.26	0.11	0.46	1.15	0.82	0.39	0.20
95126	T18	150	1,939	0	0	350	0.73	0.07	0.26	0.29	0.46	1.87	0.16	1.47	0.34	2.69	34.21	22.00	7.90	2.93
95126	T19	150	2,050	0	0	350	3.08	0.26	0.94	1.03	1.88	7.86	0.85	4.87	2.56	7.52	79.45	59.80	31.61	13.67
951127	T20	149	1,967	19	253	300	0.18	0.03	0.07	0.09	0.14	0.48	0.06	0.54	0.16	1.10	2.74	2.66	1.57	0.78
951127	T21	150	1,964	20	259	300	0.12	0.03	0.07	0.09	0.12	(0.37)	0.05	0.57	0.15	1.24	2.23	1.24	0.99	0.21
951128	T22	150	2,204	27	397	325	0.05	(0.02)	0.03	0.03	0.04	0.11	0.02	0.20	0.05	0.44	0.43	0.48	0.34	0.21
951128	T23	150	1,975	27	356	325	0.05	0.02	0.03	0.03	0.04	0.14	0.02	0.27	0.09	0.70	0.38	0.43	0.34	0.23

Appendix A -- Measured emissions characteristics.

DATE	TEST I.D.	TRONA lb/h	TRONA mg/dsm^3	PAC lb/h	PAC mg/dsm^3	Ttrgt °F	TCDD ng/dsm3	PCDD ng/dsm3	HXCDD ng/dsm3	HPCDD ng/dsm3	TOTDXN ng/dsm3	TotF ng/dsm3	Tot D ng/dsm3	ITEQ ng/dsm3
							all at 7% O2							
951117	T01	150	1,938	0	0	420	6.71	9.37	9.37	10.15	116	72.9	43.4	2.98
951117	T02(HCl)	150	1,980	0	0	420								
951118	T02	150	2,065	0	0	420	5.37	4.50	4.66	4.89	91	67.4	23.4	2.15
951118	T03	150	2,008	0	0	420	4.44	4.60	5.16	5.40	87	62.9	24.4	2.14
951119	T04	150	1,994	27	359	420	1.65	2.30	2.96	3.29	37	23.8	13.4	0.92
951119	T05	150	1,960	27	353	420	0.74	0.74	1.64	1.88	15	8.0	7.0	0.34
191120	T06	0	0	0	0	420	4.09	4.89	7.37	6.33	115	87.5	28.0	3.12
951120	T07	0	0	0	0	420	3.74	4.31	6.51	6.02	98	72.3	26.0	2.49
951121	T08	150	2,011	27	361	350	0.59	1.56	3.87	4.52	20	4.9	15.1	0.30
951121	T09	149	2,090	27	374	350	0.45	1.22	2.61	3.35	17	6.2	11.2	0.30
951122	T10	151	2,041	27	365	300	5.23	8.43	7.84	5.40	154	122.9	31.1	4.20
951122	T11	150	1,989	31	416	300	0.24	0.25	0.69	0.80	6.0	2.9	3.0	0.16
951123	T12	151	1,995	0	0	300	7.29	8.71	7.68	6.34	151	115.6	35.1	4.11
951123	T13	150	2,033	0	0	300	5.53	7.66	8.69	7.90	127	89.6	37.2	3.52
951124	T14	150	1,920	27	345	350	0.21	0.36	0.87	1.11	7.4	3.6	3.7	0.19
951124	T15	150	1,925	27	347	350	0.09	0.18	0.44	0.53	3.4	1.5	1.9	0.09
951125	T16	150	1,902	20	251	350	0.21	0.26	0.73	0.73	5.3	2.6	2.7	0.15
951125	T17	150	2,057	19	261	350	0.16	0.20	0.54	0.50	4.5	2.7	1.9	0.11
95126	T18	150	1,939	0	0	350	3.50	2.93	3.83	3.01	83	67.4	16.0	2.17
95126	T19	150	2,050	0	0	350	11.96	17.94	15.38	10.25	250	187.1	63.0	6.56
951127	T20	149	1,967	19	253	300	0.44	0.64	1.10	1.10	12	7.9	4.4	0.35
951127	T21	150	1,964	20	259	300	1.57	0.79	1.41	1.16	11	4.8	6.2	0.24
951128	T22	150	2,204	27	397	325	0.11	0.16	0.39	0.39	3.0	1.5	1.5	0.09
951128	T23	150	1,975	27	356	325	0.09	0.13	0.40	0.51	3.3	1.5	1.8	0.08

DATA VARIABLES USED IN APPENDIX A

TESTDATE	When the test was conducted--year, month, day.
SAMPLEID	Run designator in report.
SO2RGNT	Lb\hr addition rate of acid gas control reagent.
HGRGNT	Lb\hr addition rate of mercury control reagent.
FGO_2	% flue gas oxygen.
CO	Carbon monoxide concentration (ppmdv @ 7% O_2).
SO_X	Sulfur dioxide (ppmdv @ 7% O_2) at the sampling point.
NO_X	Oxides of nitrogen as NO2 (ppmdv @ 7% O_2) at the sampling point.
TNMHC	Total nonmethane HC as C (ppmdv @ 7% O_2) at the sampling point.
FGTEMP	Temperature at the sampling point.
DSCFM	Flue gas flow rate.
HF	Hydrogen Fluoride concentration (ppmdv @ 7% O_2) at the sampling point.
Cl_2	Chlorine gas concentration (ppmdv @ 7% O_2) measured using Method 26 back half impingers.
HCl	Hydrogen Chloride concentration (ppmdv @ 7% O_2) at the sampling point.
TSP	Particulate (front and back half) at the sampling point in mg/dscm @ 7% O_2.
CD	Cadmium (ug/dscm @ 7% O_2).
PB	Lead (ug/dscm @ 7% O_2).
HG	Mercury (ug/dscm @ 7% O_2).
TOTDXN	Total of all Dioxin and Furan isomers (ng/dscm @ 7% O_2).
AS	Arsenic (ug/dscm @ 7% O_2).
SB	Antimony (ug/dscm @ 7% O_2).
LI	Lithium (ug/dscm @ 7% O_2).
AL	Aluminum (ug/dscm @ 7% O_2).
BA	Barium (ug/dscm @ 7% O_2).
BE	Beryllium (ug/dscm @ 7% O_2).
CA	Calcium (ug/dscm @ 7% O_2).
CR	Chromium (ug/dscm @ 7% O_2).
COB	Cobalt (ug/dscm @ 7% O_2).
CU	Copper (ug/dscm @ 7% O_2).
FE	Iron (ug/dscm @ 7% O_2).
MG	Magnesium (ug/dscm @ 7% O_2).
MN	Manganese (ug/dscm @ 7% O_2).
MO	Molybdenum (ug/dscm @ 7% O_2).
NI	Nickel (ug/dscm @ 7% O_2).
P	Phosphorous (ug/dscm @ 7% O_2).
K	Potassium (ug/dscm @ 7% O_2).
AG	Silver (ug/dscm @ 7% O_2).
NA	Sodium (ug/dscm @ 7% O_2).
ST	Strontium (ug/dscm @ 7% O_2).
TL	Thallium (ug/dscm @ 7% O_2).
V	Vanadium (ug/dscm @ 7% O_2).
ZN	Zinc (ug/dscm @ 7% O_2).
B	Boron (ug/dscm @ 7% O_2).
SI	Silicon (ug/dscm @ 7% O_2).
SN	Tin (ug/dscm @ 7% O_2).
TI	Titanium (ug/dscm @ 7% O_2).
DCB2	Dichlorobenzene(1,2) (ng/dscm @ 7% O_2).
DCB3	Dichlorobenzene(1,3) (ng/dscm @ 7% O_2).
DCB4	Dichlorobenzene(1,4) (ng/dscm @ 7% O_2).
TRICB23	Trichlorobenzene(1,2,3) (ng/dscm @ 7% O_2).
TRICB24	Trichlorobenzene(1,2,4) (ng/dscm @ 7% O_2).
TRICB35	Trichlorobenzene(1,3,5) (ng/dscm @ 7% O_2).
TCB234	Tetrachlorobenzene(1,2,3,4) (ng/dscm @ 7% O_2).

TCB235	Tetrachlorobenzene(1,2,3&4,5) (ng/dscm @ 7% O_2).
PECB	Total Pentachlorobenzene (ng/dscm @ 7% O_2).
HXCB	Total Hexachlorobenzene (ng/dscm @ 7% O_2).
DCP23	Dichlorophenol(2,3) (ng/dscm @ 7% O_2).
DCP24	Dichlorophenol(2,4) (ng/dscm @ 7% O_2).
DCP25	Dichlorophenol(2,5) (ng/dscm @ 7% O_2).
DCP26	Dichlorophenol(2,6) (ng/dscm @ 7% O_2).
DCP34	Dichlorophenol(3,4) (ng/dscm @ 7% O_2).
DCP35	Dichlorophenol(3,5) (ng/dscm @ 7% O_2).
TRICP234	Trichlorophenol(2,3,4) (ng/dscm @ 7% O_2).
TRICP235	Trichlorophenol(2,3,5) (ng/dscm @ 7% O_2).
TRICP236	Trichlorophenol(2,3,6) (ng/dscm @ 7% O_2).
TRICP245	Trichlorophenol(2,4,5) (ng/dscm @ 7% O_2).
TRICP246	Trichlorophenol(2,4,6) (ng/dscm @ 7% O_2).
TRICP345	Trichlorophenol(3,4,5) (ng/dscm @ 7% O_2).
TCP2345	Tetrachlorophenol(2,3,4,5) (ng/dscm @ 7% O_2).
TCP2346	Tetrachlorophenol(2,3,4,6) (ng/dscm @ 7% O_2).
TCP2356	Tetrachlorophenol(2,3,5,6) (ng/dscm @ 7% O_2).
PECP	Total pentachlorophenol (ng/dscm @ 7% O_2).
MONOCBP	Chlorobiphenyl (ng/dscm @ 7% O_2).
DICBP	Dichlorobiphenyl (ng/dscm @ 7% O_2).
TRICBP	Trichlorobiphenyl (ng/dscm @ 7% O_2).
TCBP	Tetrachlorobiphenyl (ng/dscm @ 7% O_2).
PECBP	Pentachlorobiphenyl (ng/dscm @ 7% O_2).
HXCBP	Hexachlorobiphenyl (ng/dscm @ 7% O_2).
HPCBP	Heptachlorobiphenyl (ng/dscm @ 7% O_2).
OCBP	Octachlorobiphenyl (ng/dscm @ 7% O_2).
NONACBP	Nonachlorobiphenyl (ng/dscm @ 7% O_2).
DECBP	Decachlorobiphenyl (ng/dscm @ 7% O_2).

PCBS	Total polychlorinated biphenyls (ng/dscm @ 7% O_2).
NAPHLENE	Naphthalene (ng/dscm @ 7% O_2).
ACENPHLN	Acenaphthylene (ng/dscm @ 7% O_2).
ACENATHN	Acenaphthene (ng/dscm @ 7% O_2).
FLUORENE	Fluorene (ng/dscm @ 7% O_2).
PHENATHN	Phenanthrene (ng/dscm @ 7% O_2).
ANTRACNE	Anthracene (ng/dscm @ 7% O_2).
FLUANTHN	Fluoranthene (ng/dscm @ 7% O_2).
PYRENE	Pyrene (ng/dscm @ 7% O_2).
BENZANTH	Benzo(a)anthracene (ng/dscm @ 7% O_2).
CHRYSENE	Chrysene (ng/dscm @ 7% O_2).
BNZBFLAN	Benzo(b)fluoranthene (ng/dscm @ 7% O_2).
BNZKFLAN	Benzo(k)fluoranthene (ng/dscm @ 7% O_2).
BENAPYRN	Benzo(a)pyrene (ng/dscm @ 7% O_2).
INDEPYRN	Indeno(1,2,3-cd)pyrene (ng/dscm @ 7% O_2).
DIBNZANT	Dibenz(a,h)anthracene (ng/dscm @ 7% O_2).
BNZPERLN	Benzo(g,h,i)perylene (ng/dscm @ 7% O_2).
TETRALIN	Tetralin (ng/dscm @ 7% O_2).
QUINOLN	Quinoline (ng/dscm @ 7% O_2).
MTLNAPH2	Methylnaphthalene(2) (ng/dscm @ 7% O_2).
MTLNAPH1	Methylnaphthalene(1) (ng/dscm @ 7% O_2).
BIPHNYL	Biphenyl (ng/dscm @ 7% O_2).
CHLNAP2	2-chloronaphthalene (ng/dscm @ 7% O_2).
BNZAFLNE	Benzo(a)fluorene (ng/dscm @ 7% O_2).
BNZBFLNE	Benzo(b)fluorene (ng/dscm @ 7% O_2).
TERPHNLM	Terphenyl(m) (ng/dscm @ 7% O_2).
TERPHNLO	Terphenyl(o) (ng/dscm @ 7% O_2).
TERPHNLP	Terphenyl(p) (ng/dscm @ 7% O_2).
MTHANCE2	Methylanthracene(2) (ng/dscm @ 7% O_2).
MTHPHN1	Methylphenanthrene(1) (ng/dscm @ 7% O_2).

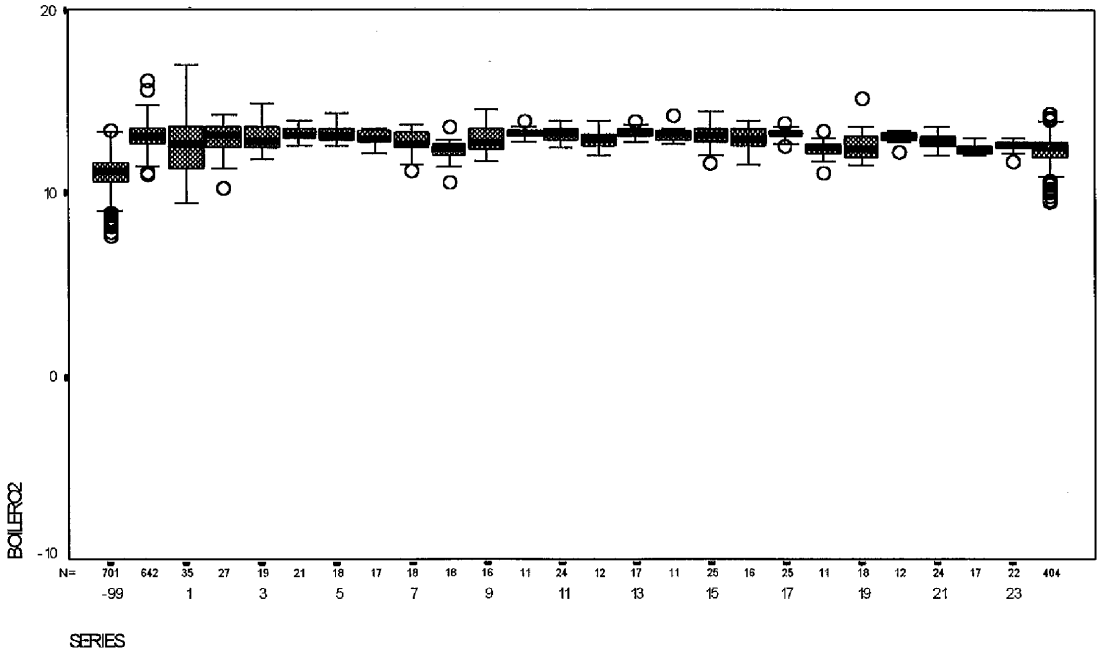
MTHPHN9	Methylphenanthrene(9) (ng/dscm @ 7% O_2).
DIMTHAN	Dimethylanthracene(9,10) (ng/dscm @ 7% O_2).
BENZBNTH	Benzo(b)anthracene (ng/dscm @ 7% O_2).
TRIPNLNE	Triphenylene (ng/dscm @ 7% O_2).
BNZEPYRN	Benzo(e)pyrene (ng/dscm @ 7% O_2).
PERYLENE	Perylene (ng/dscm @ 7% O_2).
DIMBZAN	Dimethylbenzo(a)anthracene(7,12) (ng/dscm @ 7% O_2).
MTHCLAN	Methylcholanthrene(3) (ng/dscm @ 7% O_2).
PICENE	Picene (ng/dscm @ 7% O_2).
CORONENE	Coronene (ng/dscm @ 7% O_2).
DIBZPYRN	Dibenzo(a,c,)pyrene (ng/dscm @ 7% O_2).
TCDF2378	2,3,7,8-TetraCDF (ng/dscm @ 7% O_2).
TCDD2378	2,3,7,8-TetraCDD (ng/dscm @ 7% O_2).
PCDF1	1,2,3,7,8-PentaCDF (ng/dscm @ 7% O_2).
PCDF4	2,3,4,7,8-PentaCDF (ng/dscm @ 7% O_2).
PCDD1	1,2,3,7,8-PentaCDD (ng/dscm @ 7% O_2).
HXCDF14	1,2,3,4,7,8-HexaCDF (ng/dscm @ 7% O_2).
HXCDF16	1,2,3,6,7,8-HexaCDF (ng/dscm @ 7% O_2).
HXCDF46	2,3,4,6,7,8-HexaCDF (ng/dscm @ 7% O_2).
HXCDF19	1,2,3,7,8,9-HexaCDF (ng/dscm @ 7% O_2).
HXCDD14	1,2,3,4,7,8-HexaCDD (ng/dscm @ 7% O_2).
HXCDD16	1,2,3,6,7,8-HexaCDD (ng/dscm @ 7% O_2).
HXCDD19	1,2,3,7,8,9-HexaCDD (ng/dscm @ 7% O_2).
HPCDF146	1,2,3,4,6,7,8-Hepta-CDF (ng/dscm @ 7% O_2).
HPCDF149	1,2,3,4,7,8,9-Hepta-CDF (ng/dscm @ 7% O_2).
HPCDD146	1,2,3,4,6,7,8-Hepta-CDD (ng/dscm @ 7% O_2).
OCDF	OctaCDF (ng/dscm @ 7% O_2).
OCDD	OctaCDD (ng/dscm @ 7% O_2).
TCDF	Summe TetraCDF (ng/dscm @ 7% O_2).
PCDF	Summe PentaCDF (ng/dscm @ 7% O_2).
HXCDF	Summe HexaCDF (ng/dscm @ 7% O_2).
HPCDF	Summe HeptaCDF (ng/dscm @ 7% O_2).
TCDD	Summe TetraCDD (ng/dscm @ 7% O_2).
PCDD	Summe PentaCDD (ng/dscm @ 7% O_2).
HXCDD	Summe HexaCDD (ng/dscm @ 7% O_2).
HPCDD	Summe HeptaCDD (ng/dscm @ 7% O_2).

APPENDIX B

PLANT OPERATING DATA SUMMARY STATISTICS AND BOX PLOTS

This Appendix contains box plots summarizing the plant performance characteristics the week before testing began (Series = -99); times between test runs (Series = 0); during each test (Series = 1 through 23); and for the week after testing was completed (Series = 99).

The variable labels used on the vertical axis of each box plot are defined in the table following the box plots. The test sum averages for each run and non-test time period are provided at the end of this section.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10
0
-10
BOILERO2
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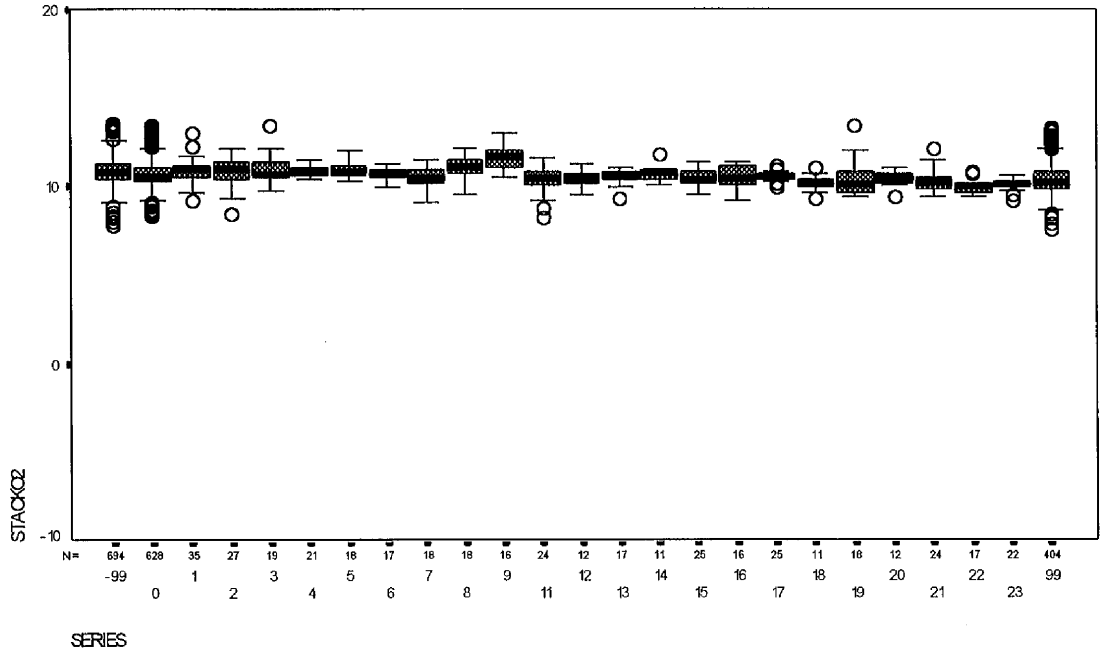
-99 1 3 5 7 9 11 13 15 17 19 21 23
SERIES


20
10
0
-10
STACKO2
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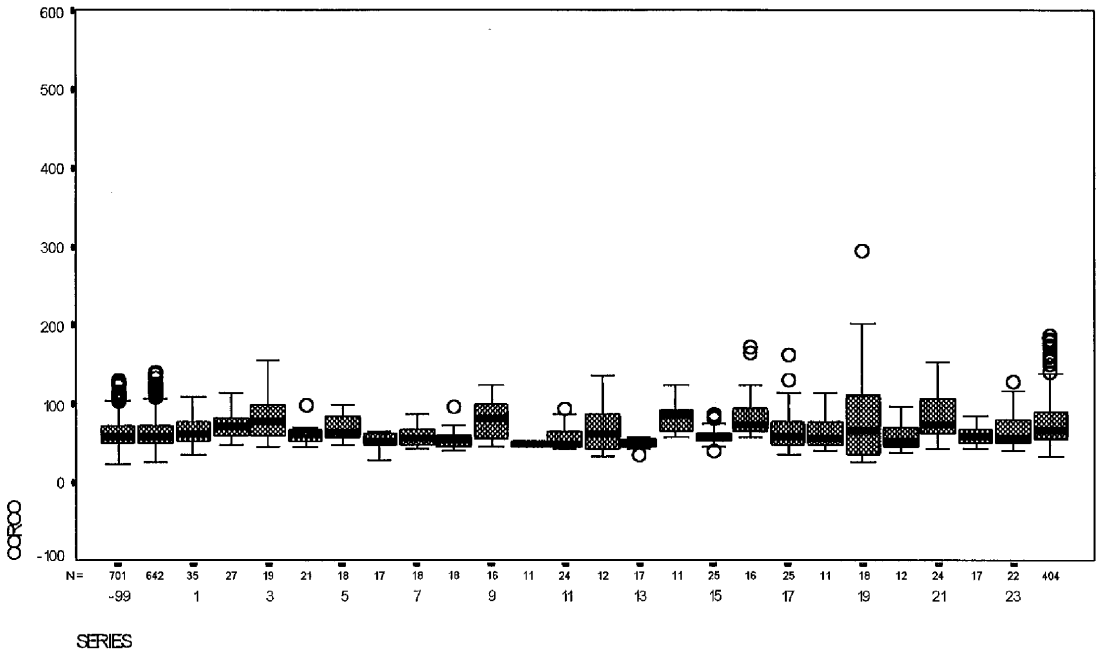
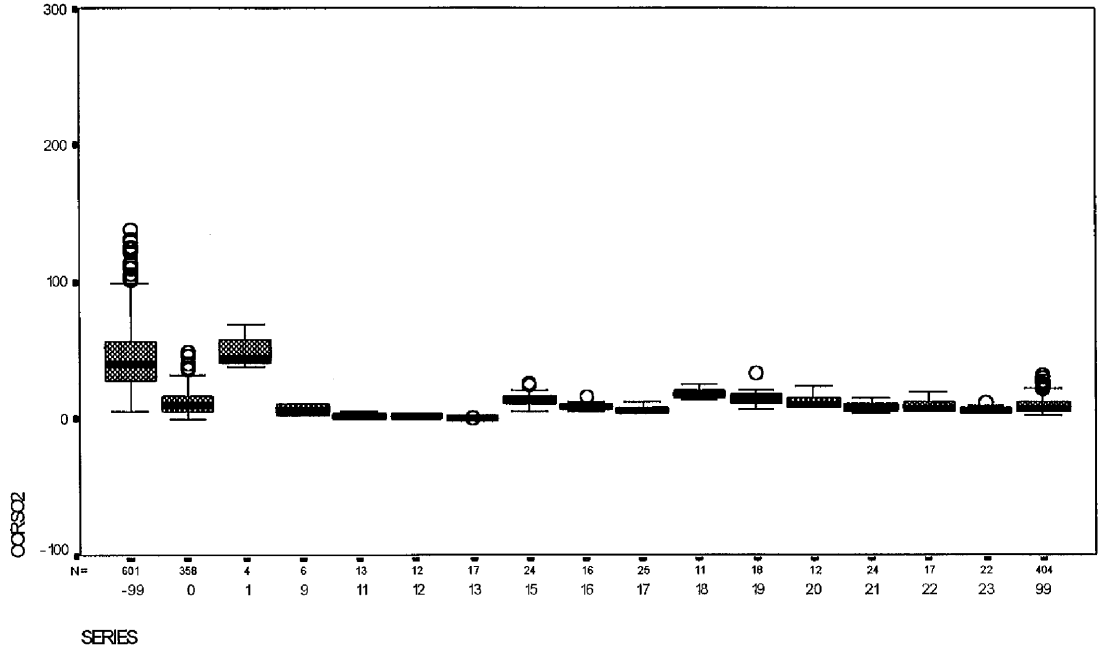
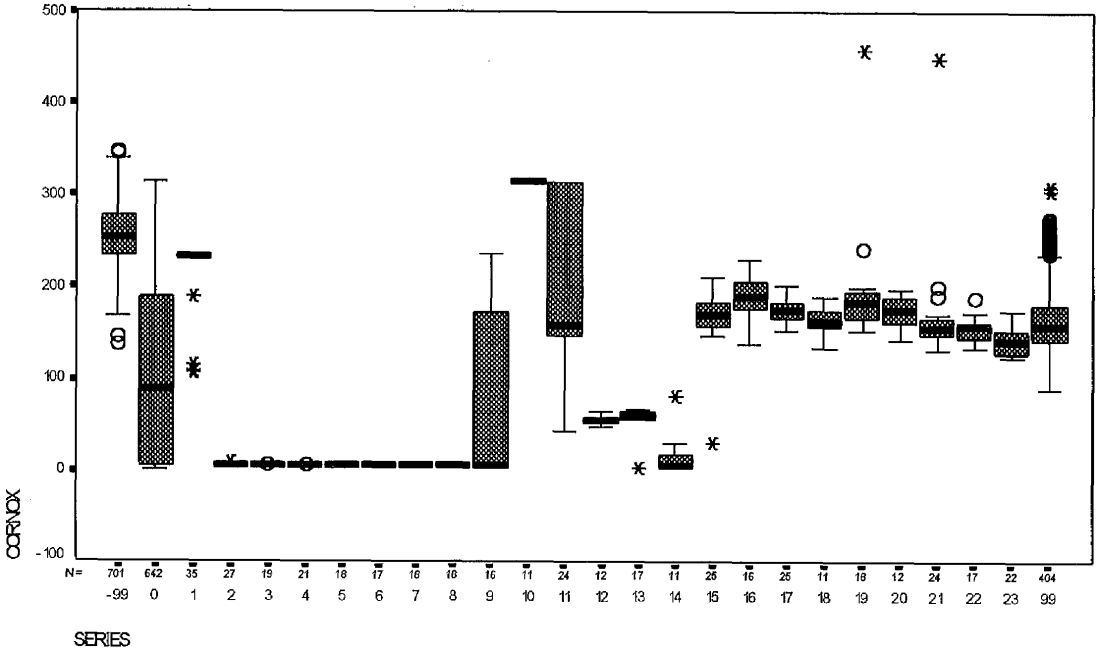
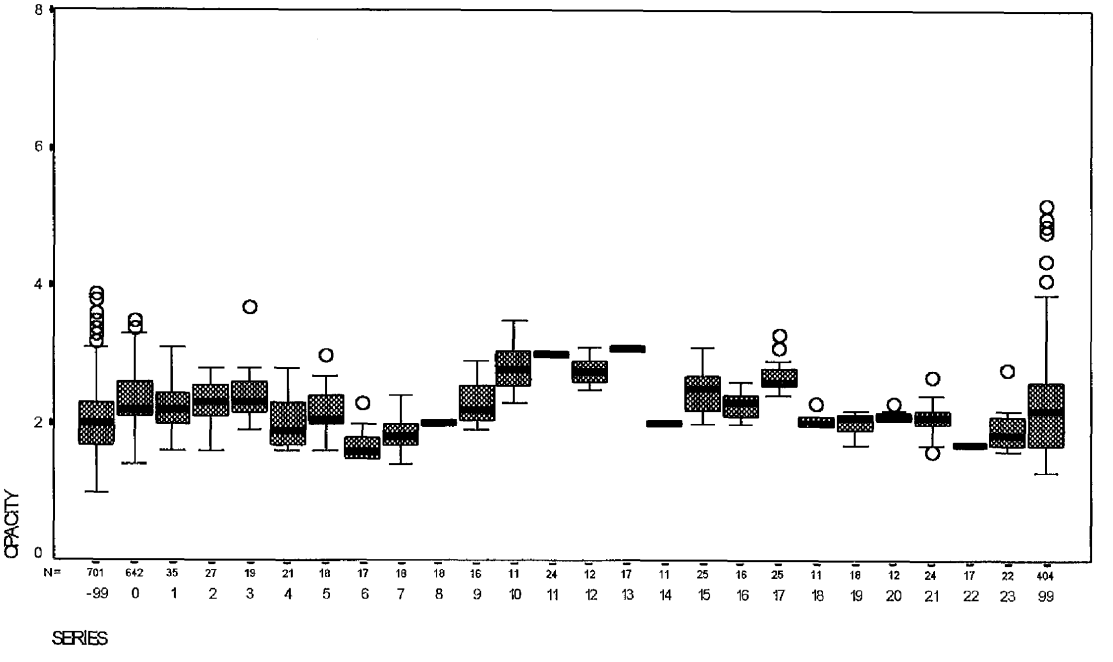
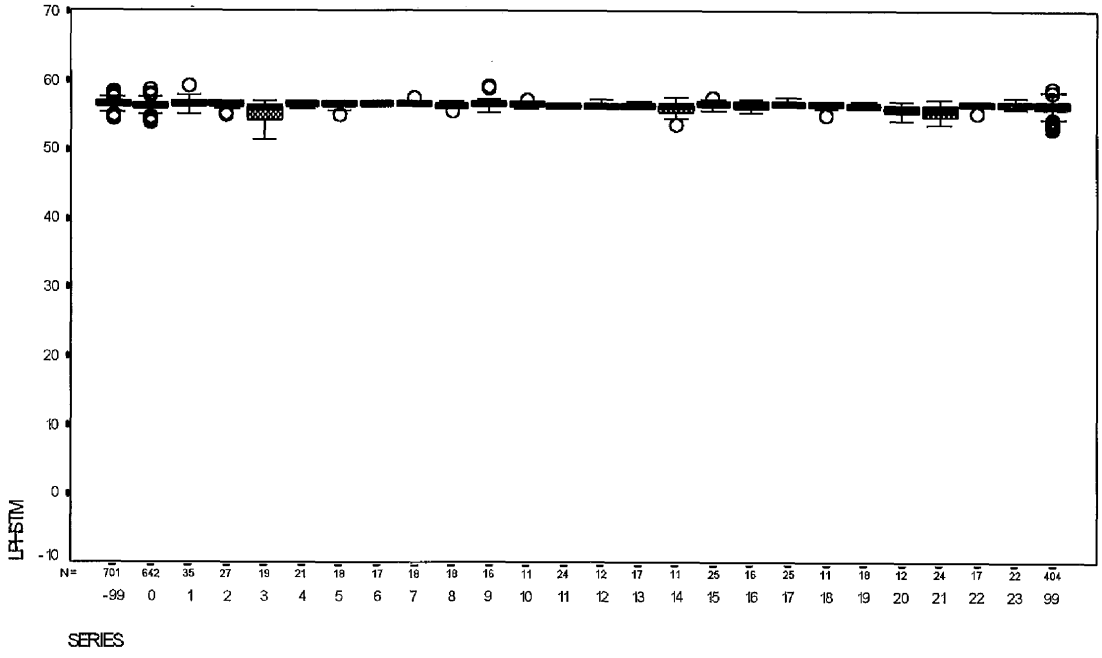
-99 1 3 5 7 9 12 14 16 18 20 22 99
0 2 4 6 8 11 13 15 17 19 21 23
SERIES


600
500
400
300
200
100
0
-100
CCRCO
N= 701 642 35 27 19 21 18 17 18 18 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
-99 1 3 5 7 9 11 13 15 17 19 21 23
SERIES


300
200
100
0
-100
CCRSO2
N= 601 358 4 6 13 12 17 24 16 25 11 18 12 24 17 22 404
-99 0 1 9 11 12 13 15 16 17 18 19 20 21 22 23 99
SERIES


500
400
300
200
100
0
-100
CORNOX
N= 701 642 35 27 19 21 18 17 16 16 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


8
6
4
2
0
OPACITY
N= 701 642 35 27 19 21 18 17 16 18 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


LPHSTM
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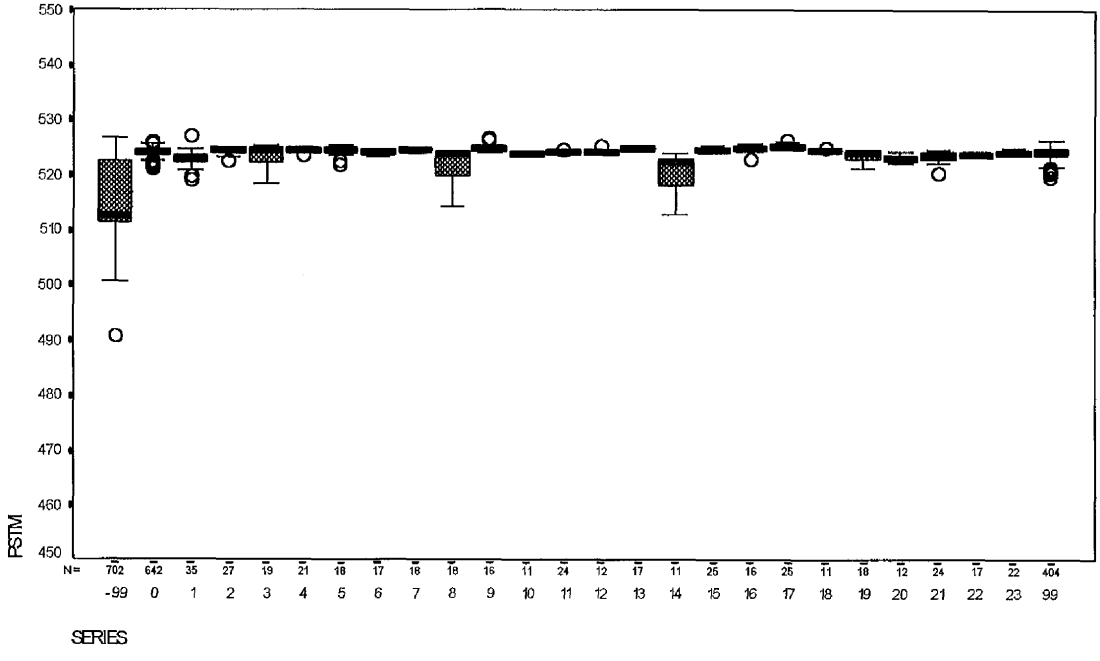
60
50
40
30
20
10
0
-10
N= 701 642 35 27 19 21 18 17 18 18 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


PSTM
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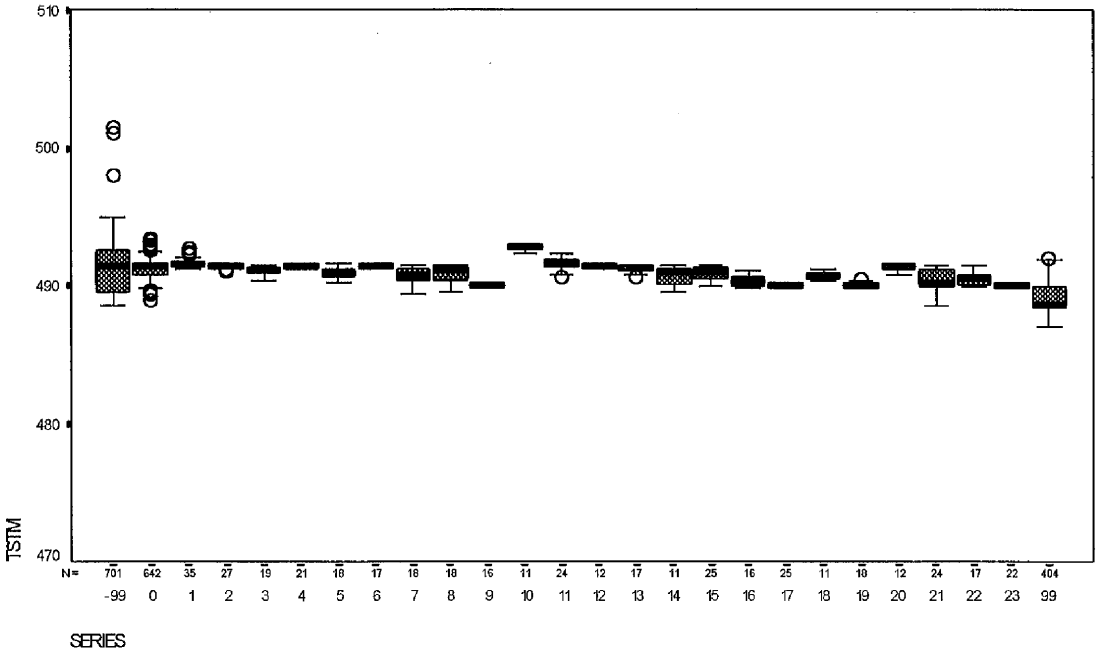
540
530
520
510
500
490
480
470
460
450
N= 702 642 35 27 19 21 18 17 18 18 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


510
500
490
480
470
TSTM
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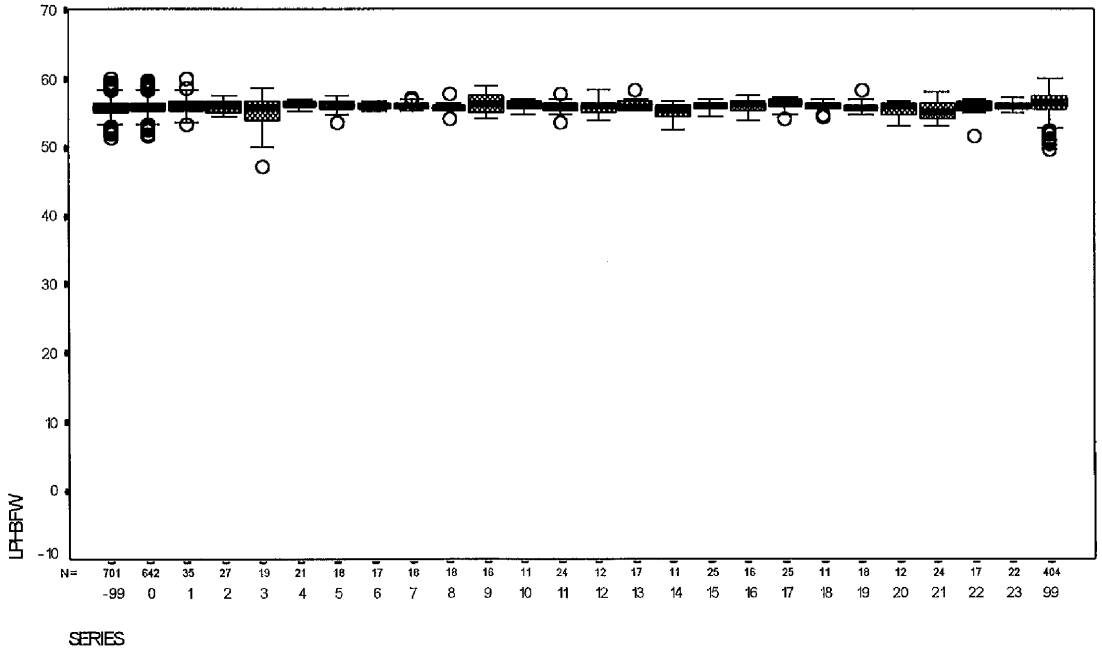
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


70
60
50
40
30
20
10
0
-10
LPHBFW
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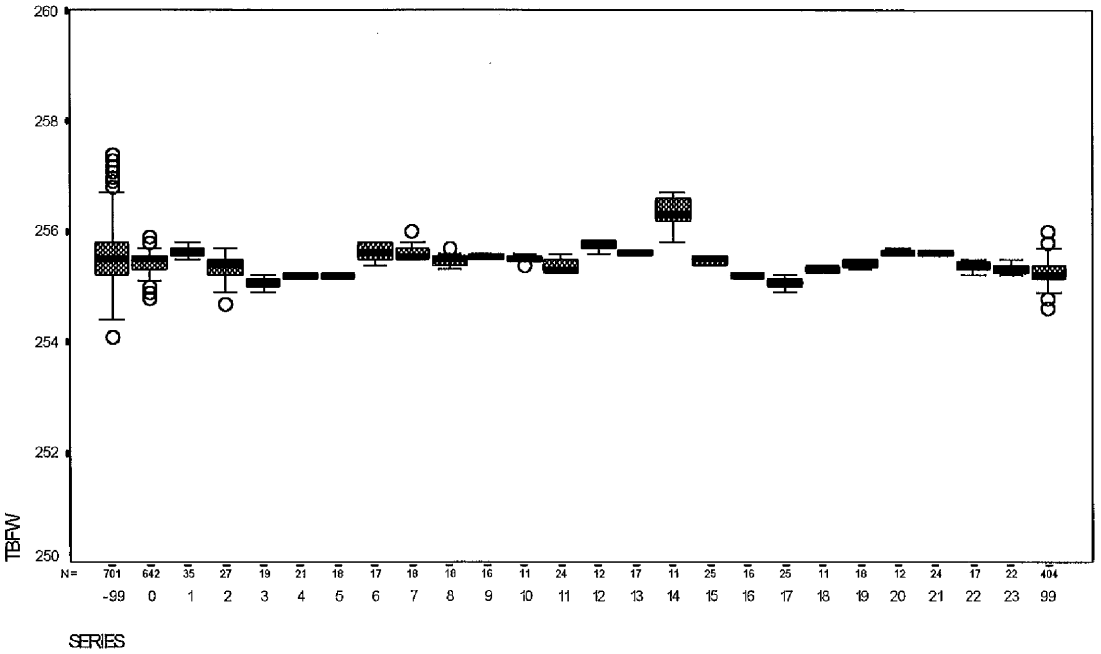
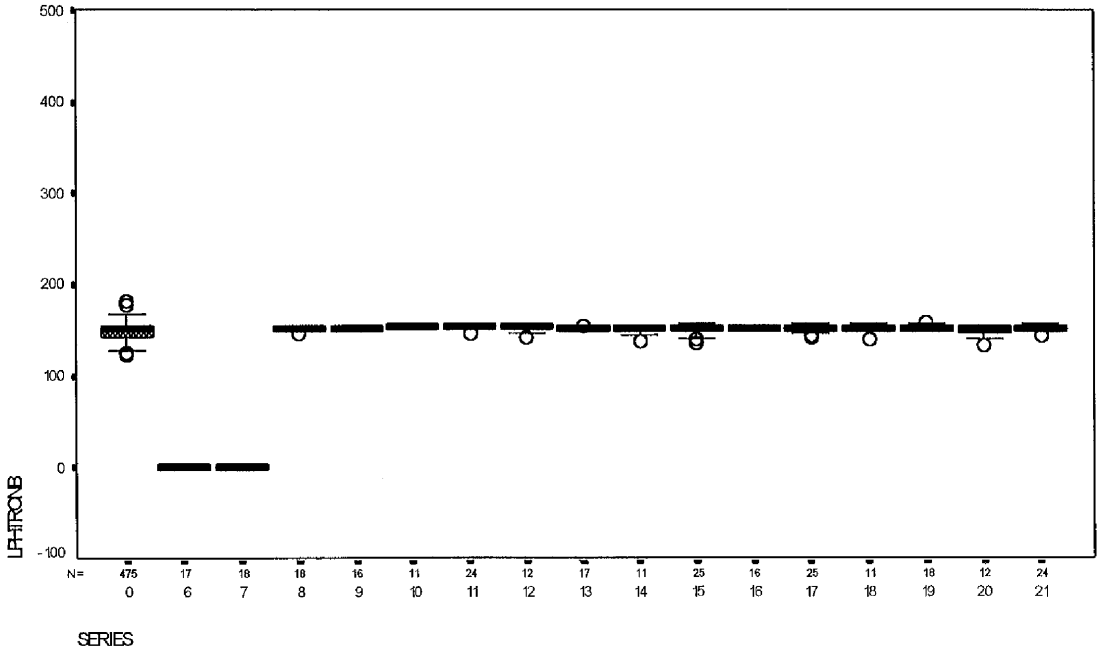
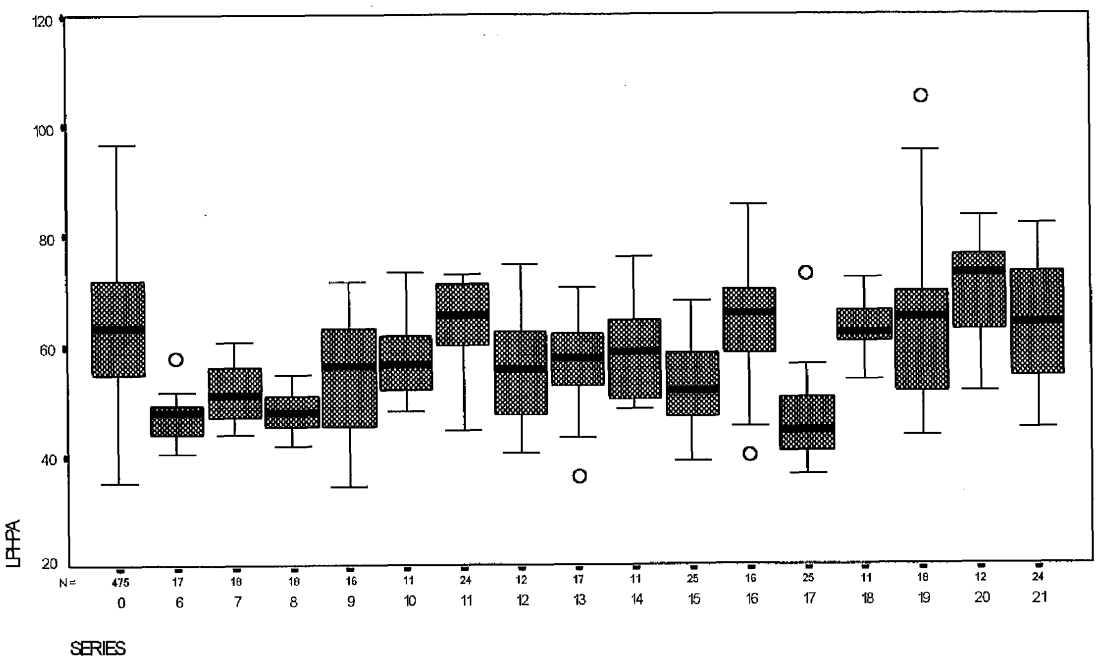
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


TBRW
260
258
256
254
252
250
N= 701 642 35 27 19 21 18 17 18 18 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


LPHTROUB
500
400
300
200
100
0
-100
N= 475 17 18 18 16 11 24 12 17 11 25 16 25 11 18 12 24
0 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
SERIES


120
100
80
60
40
20
LRPA
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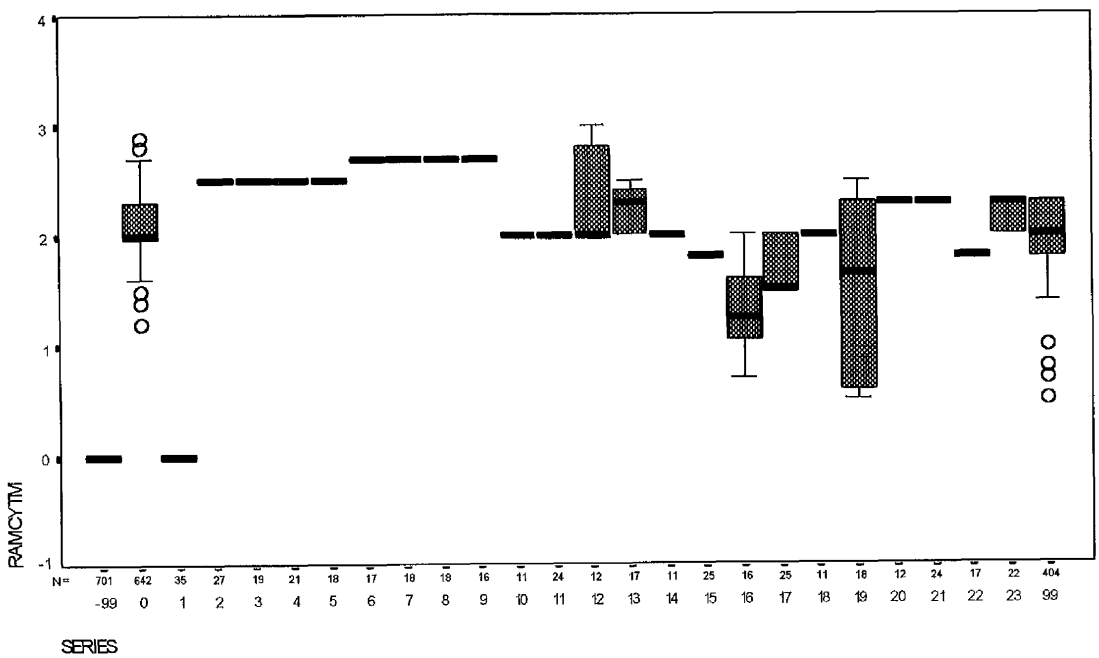
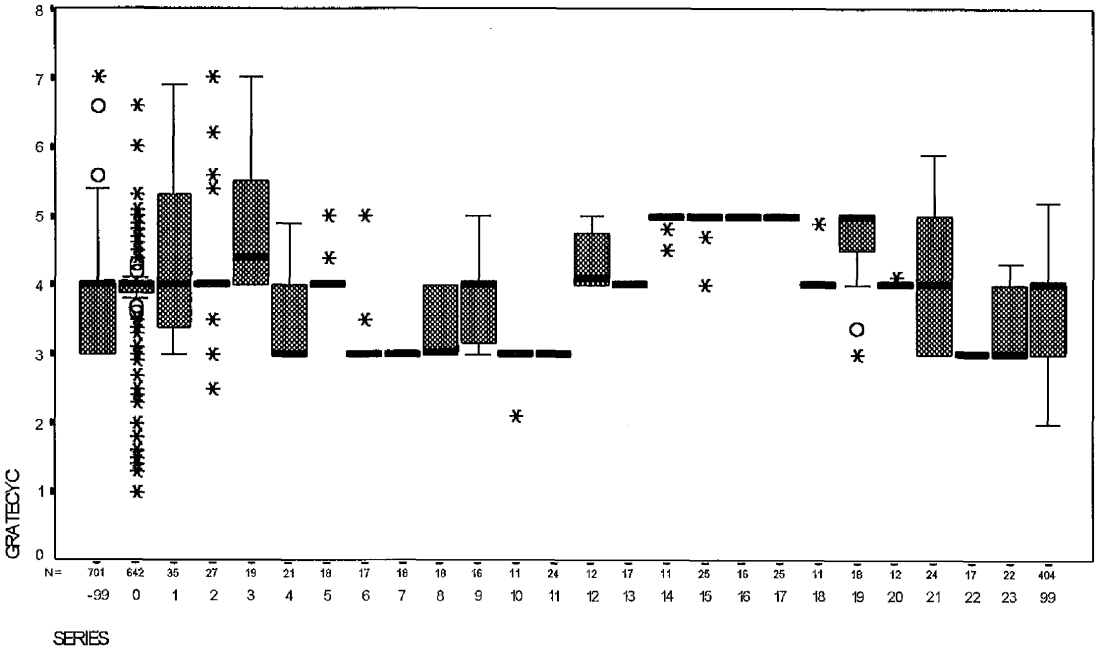
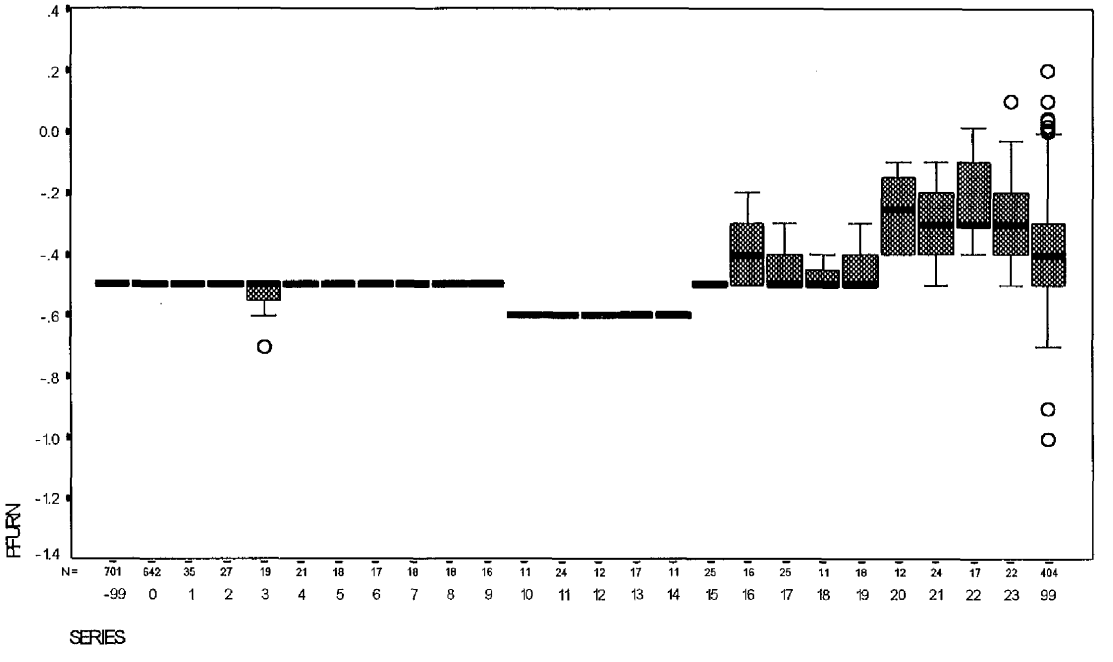
0 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
SERIES


4
3
2
1
0
-1
RAMCYTM
N= 701 642 35 27 19 21 18 17 18 18 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


GRATECYC
SERIES
N= 701 642 35 27 19 21 18 17 18 18 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99


PFLURN
SERIES
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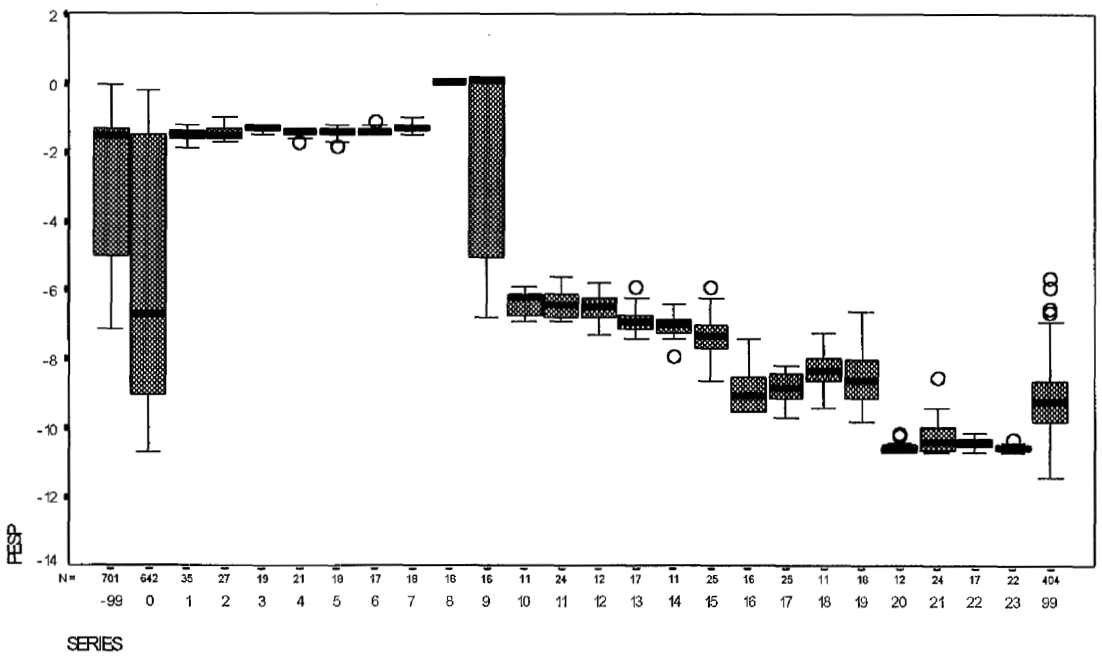
RESP
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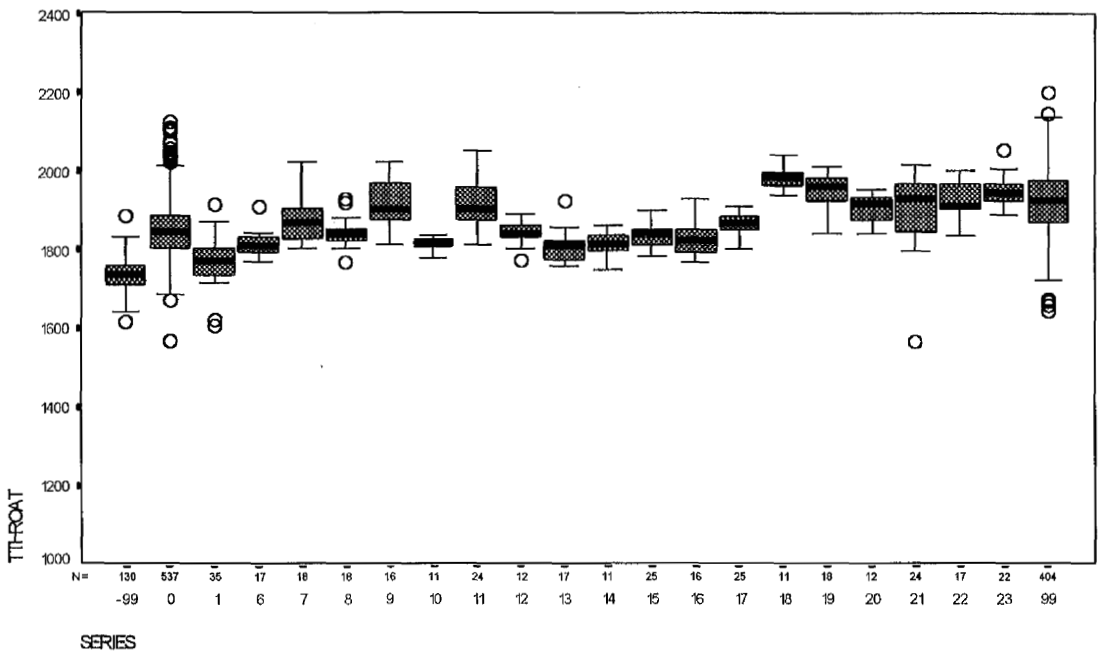
-2
-4
-6
-8
-10
-12
-14
N= 701 642 35 27 19 21 18 17 18 16 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
-99 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


TTHROAT
2400
2200
2000
1800
1600
1400
1200
1000
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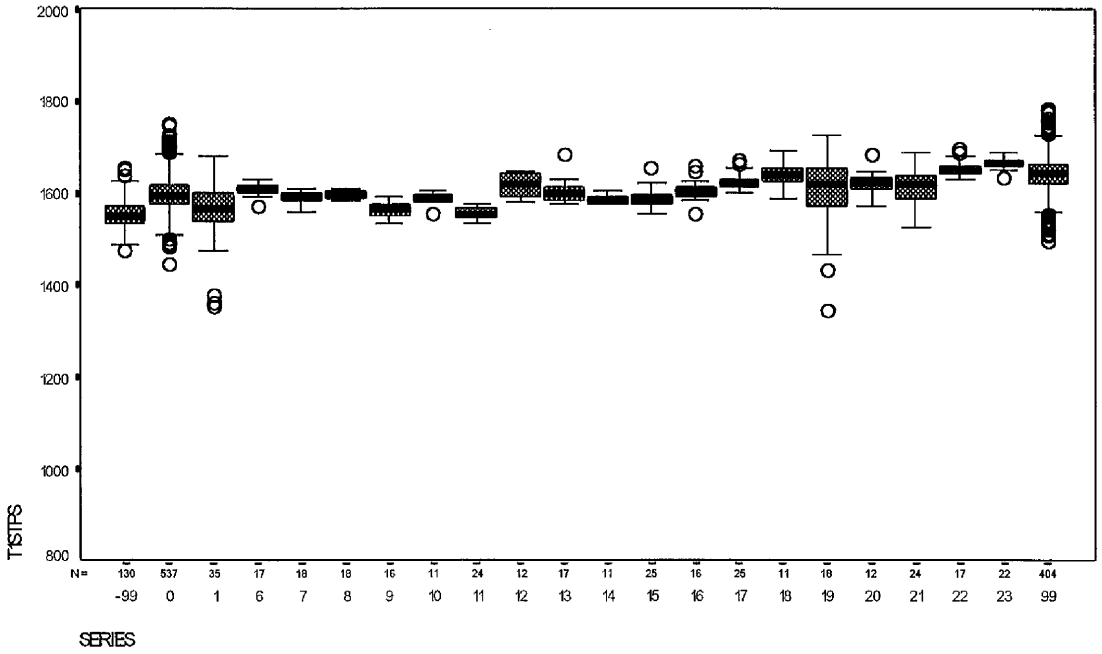
-99 0 1 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 99
SERIES


T1STPS
2000
1800
1600
1400
1200
1000
800
N= 130 537 35 17 18 18 16 11 24 12 17 11 25 16 25 11 18 12 24 17 22 404
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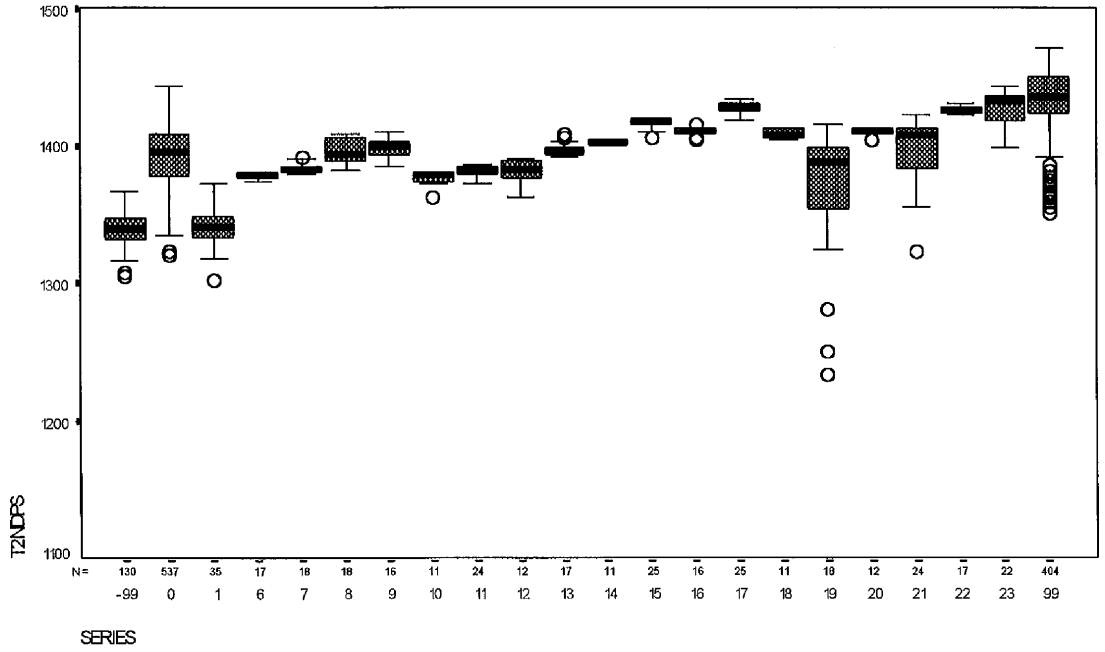
SERIES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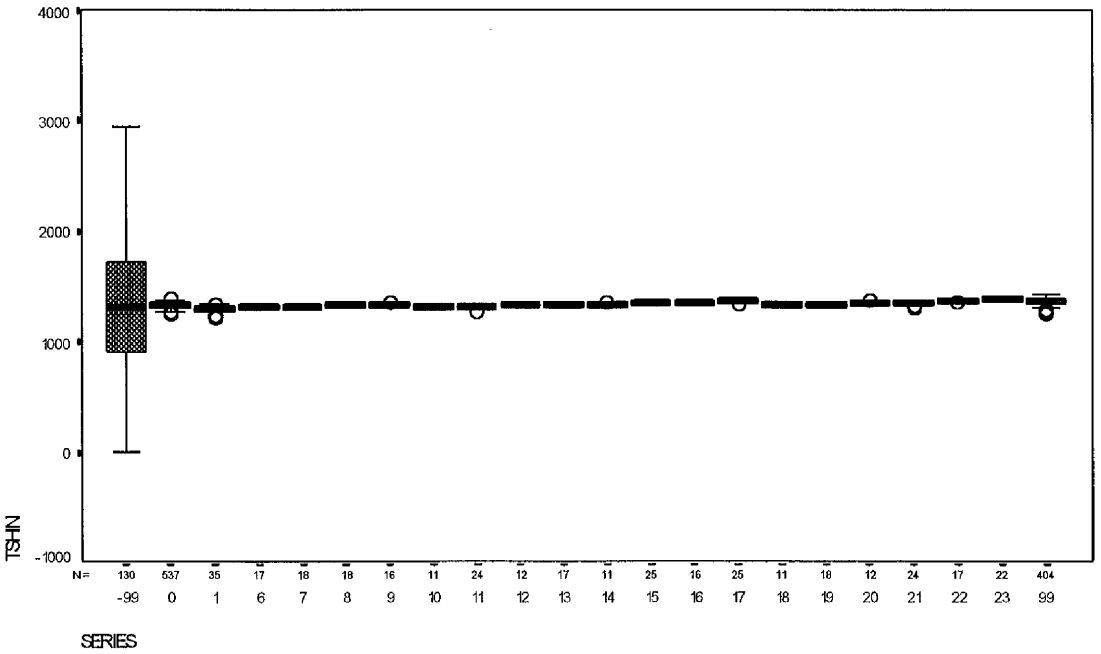
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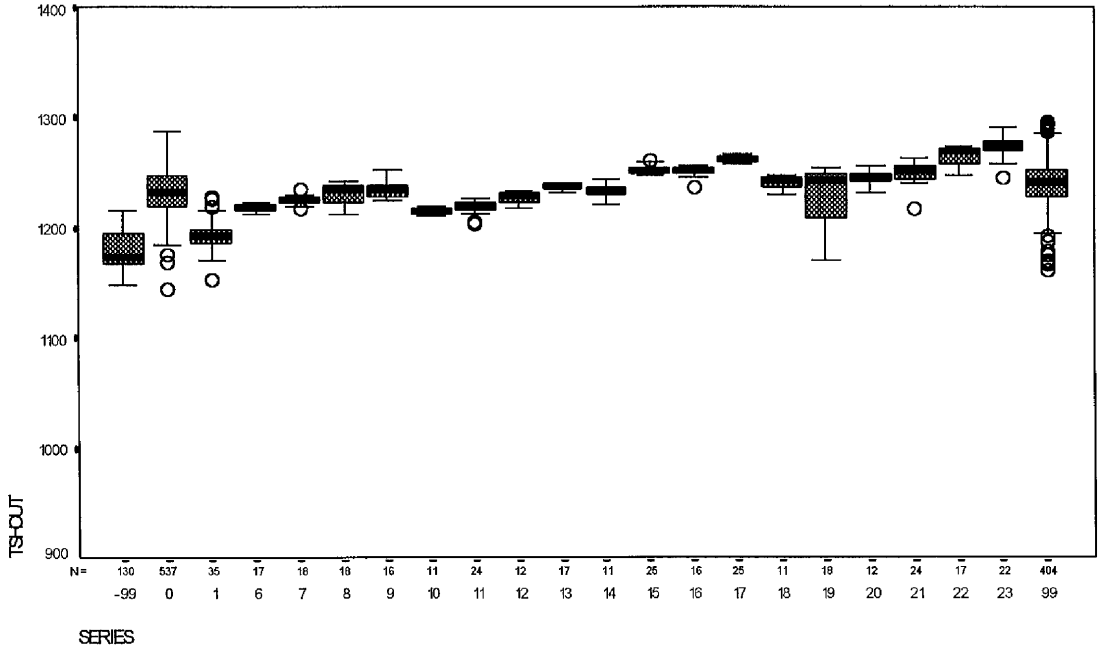
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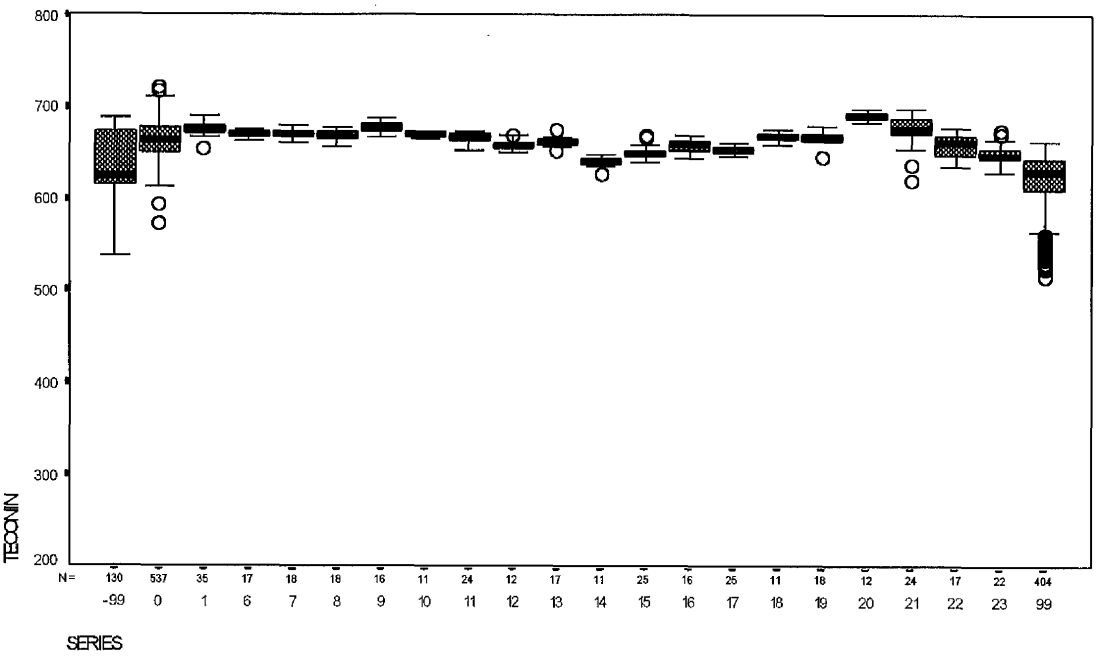
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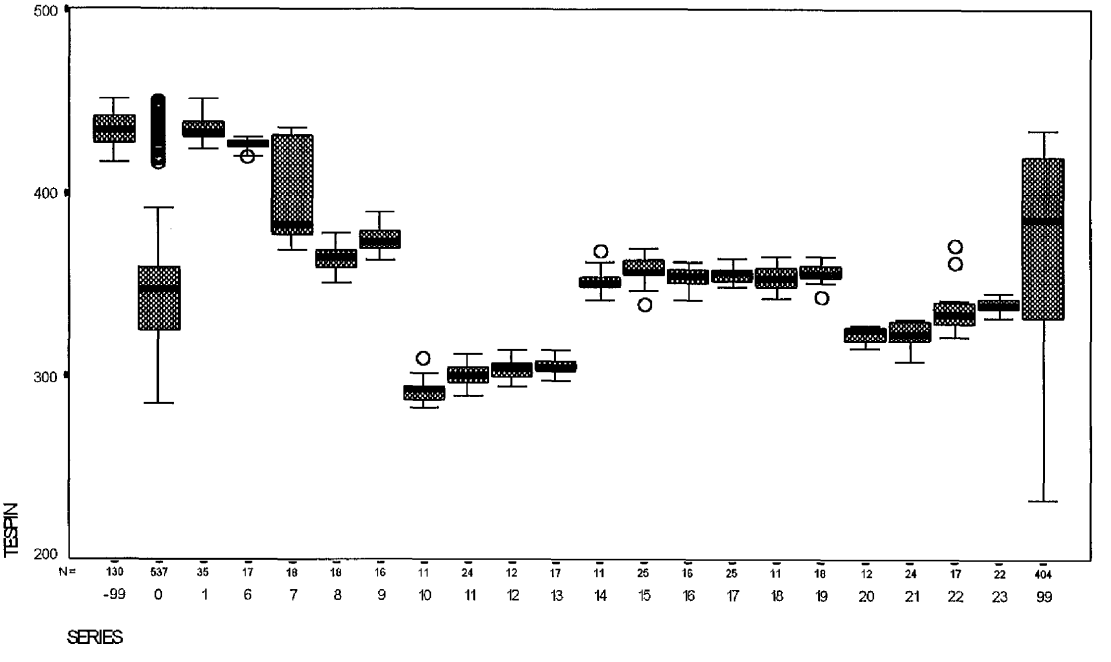
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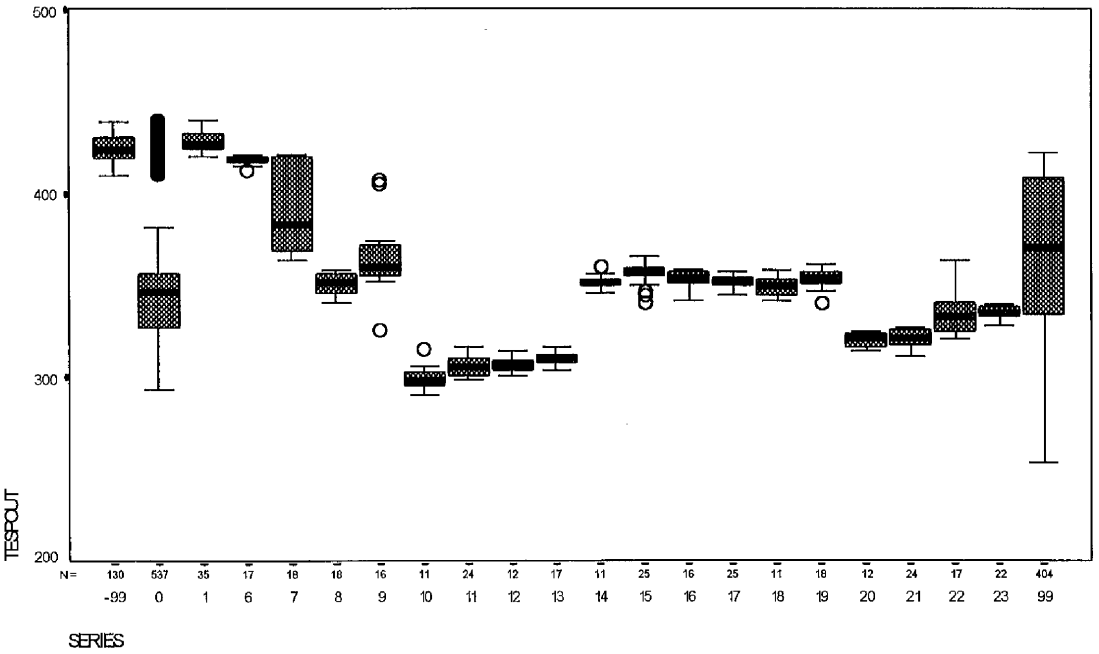
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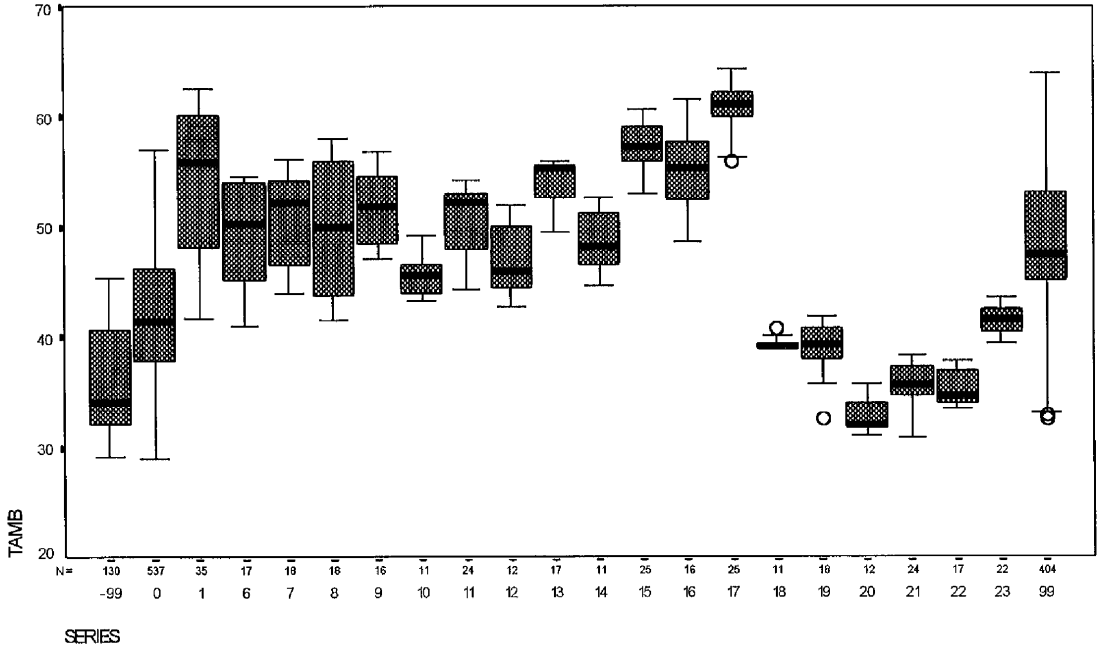
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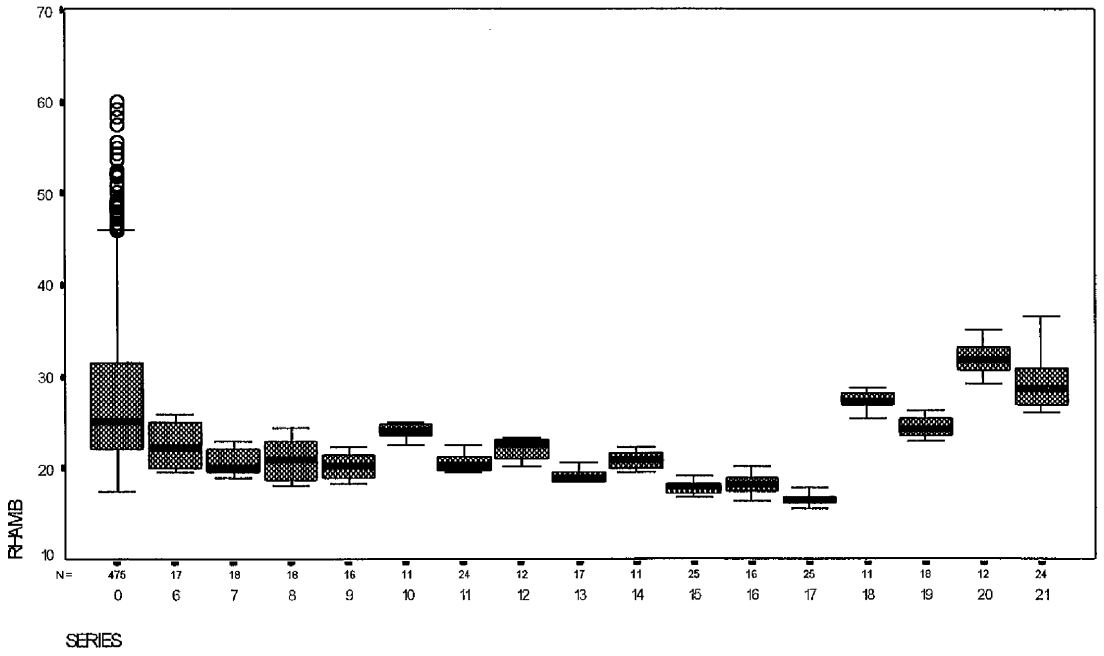
SERIES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SERIES

Appendix B: Plant Operating Characteristic Data Summary

		Average Furnace Temperature (F)			Flue Gas O2 (PCT)			O2 (PCT)			Furnace CO (PPM)			Corrected CO (PPM)			SO2 (PPM)		
SERIES	TEST ID	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
-99	Before	1614.9	1734.93	1885.6	7.7	11.14	16.8	0.6	10.84	18.0	19.8	51.66	500.0	24.7	67.00	500.0	0.0	29.93	243.2
0	Between	1511.7	1852.01	2123.5	-6.2	11.60	16.2	7.3	10.97	21.8	-0.5	49.50	154.0	26.6	65.35	266.0	0.0	5.87	174.0
1	T1	1289.8	1760.11	1916.5	9.5	12.64	17.0	9.2	11.01	16.2	29.6	55.34	295.2	35.3	79.31	484.1	0.0	2.63	35.9
2	T2				10.3	13.06	14.3	8.5	10.87	12.1	38.9	58.11	192.9	48.1	76.51	159.2	0.0	0.00	0.0
3	T3				11.9	13.14	14.9	9.8	10.98	13.4	36.7	60.36	110.4	45.4	88.05	222.1	0.0	0.00	0.0
4	T4				12.6	13.24	14.0	10.4	10.90	11.5	32.3	48.68	94.1	44.5	65.62	132.5	0.0	0.00	0.0
5	T5				12.6	13.28	14.4	10.3	10.87	12.0	35.7	55.75	126.4	48.5	73.95	166.9	0.0	0.00	0.0
6	T6	1766.6	1819.28	1972.0	12.2	13.00	13.6	10.0	10.69	11.3	22.7	38.18	50.2	29.0	51.84	66.0	0.0	0.00	0.0
7	T7	1800.6	1878.54	2019.5	11.2	12.74	13.8	9.1	10.50	11.5	31.3	43.30	62.6	44.1	58.04	87.6	0.0	0.00	0.0
8	T8	1768.9	1841.59	1927.3	10.6	12.33	13.7	9.6	11.06	12.2	29.7	39.10	58.6	41.3	55.56	95.9	0.0	0.00	0.0
9	T9	1810.9	1912.13	2023.5	11.8	12.93	14.6	10.5	11.60	13.0	31.5	54.21	76.7	46.8	79.13	122.8	0.0	12.31	184.0
10	T10	1778.6	1814.15	1835.4	12.8	13.29	14.0	13.7	20.66	21.8	-1.6	9.13	91.6	48.8	48.80	48.8	5.1	55.14	264.2
11	T11	1811.4	1908.18	2049.9	12.5	13.22	14.0	8.2	10.40	13.3	32.0	99.95	345.9	43.2	57.90	93.7	0.3	19.86	260.8
12	T12	1775.3	1839.53	1890.3	12.1	12.95	14.0	9.6	10.43	11.3	25.4	52.29	116.6	34.0	67.07	137.1	1.0	1.15	1.3
13	T13	1758.8	1807.84	1925.1	12.1	13.29	14.0	9.3	10.54	11.1	29.9	37.11	41.2	35.8	49.88	58.1	0.7	1.01	1.3
14	T14	1746.8	1814.67	1862.5	12.7	13.24	14.3	10.1	10.71	11.8	41.0	64.68	139.1	57.5	81.77	123.7	0.0	0.00	0.0
15	T15	1784.5	1832.98	1899.4	11.7	13.15	14.5	9.5	10.48	11.4	31.4	46.03	75.1	41.6	60.47	86.7	4.0	21.86	278.6
16	T16	1768.2	1828.78	1930.0	11.6	13.03	14.0	9.2	10.52	11.4	45.0	73.79	194.9	58.3	88.27	174.1	4.3	7.11	11.6
17	T17	1804.0	1865.94	1907.8	12.6	13.23	13.9	10.0	10.63	11.2	26.1	52.62	114.5	35.7	69.59	162.5	3.1	5.38	9.6
18	T18	1941.3	1983.75	2039.8	11.1	12.40	13.4	9.3	10.20	11.1	30.8	58.60	118.9	40.0	64.09	113.6	10.2	16.83	47.5
19	T19	1194.1	1893.80	2014.6	11.6	12.82	17.3	9.4	10.81	18.0	21.3	89.78	448.4	26.3	105.96	459.3	5.4	10.07	15.0
20	T20	1842.3	1905.53	1952.3	12.3	13.05	13.4	9.4	10.48	11.1	30.6	45.17	83.4	37.9	57.78	98.1	5.8	9.41	19.6
21	T21	1157.4	1873.25	2016.2	12.1	13.05	17.9	9.4	10.60	17.7	31.8	81.41	454.9	42.1	99.74	499.3	3.2	6.32	12.1
22	T22	1837.0	1928.87	2003.7	-6.2	10.16	13.0	9.4	9.96	10.8	33.1	49.85	84.3	42.1	60.45	85.5	4.2	7.83	14.7
23	T23	1764.7	1944.95	2056.6	11.8	12.63	13.8	9.2	10.16	11.8	32.8	57.21	144.9	41.8	71.05	173.0	3.6	5.85	16.9
99	After	1457.0	1926.92	2203.1	-6.2	11.16	15.4	7.1	10.46	14.4	24.5	63.03	305.5	33.1	78.58	346.4	2.1	9.07	127.5

		NOx (PPM)			Corrected SO2 (PPM)			Stack NOx (PPM)			Opacity (PCT)			Lance H2O (GPM)			Lance Air (PSI)		
SERIES	TEST ID	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
-99	Before	0.0	159.79	239.6	5.6	50.55	355.8	139.5	257.45	348.3	1.0	2.12	14.9						
0	Between	0.0	70.09	183.8	0.6	20.74	209.2	0.0	101.26	314.9	1.4	2.41	8.2	0.0	6.62	11.1	-0.3	80.10	88.7
1	T1	0.0	6.86	78.3	38.0	70.11	72.8	107.4	221.66	233.5	1.6	2.41	7.9						
2	T2	3.5	4.18	5.0	36.3	36.30	36.3	4.7	6.00	8.9	1.6	2.29	2.8						
3	T3	3.4	4.17	4.7	36.3	36.30	36.3	4.5	5.96	8.1	1.9	2.42	3.7						
4	T4	3.8	4.25	4.8	36.3	36.30	36.3	5.2	5.95	7.0	1.6	2.21	7.4						
5	T5	3.4	4.38	5.4	36.3	36.30	36.3	4.2	6.16	7.8	1.6	2.20	3.0						
6	T6	3.3	4.09	4.7	36.3	36.30	36.3	4.7	5.59	6.3	1.5	1.72	2.7	0.0	0.00	0.0	-0.3	-0.22	-0.2
7	T7	3.0	4.27	4.8	36.3	36.30	36.3	4.1	5.79	6.8	1.4	1.84	2.4	0.0	2.39	7.4	67.3	85.43	87.1
8	T8	3.6	4.21	4.7	36.3	36.30	36.3	5.2	6.03	7.1	1.5	1.98	2.4	2.2	3.48	3.7	86.5	86.67	86.9
9	T9	3.4	46.78	137.7	2.3	40.11	251.2	5.8	71.82	236.3	1.9	2.31	2.9	3.4	3.53	3.7	86.5	86.79	86.9
10	T10	23.5	89.61	122.6	38.5	38.50	38.5	314.9	314.90	314.9	2.3	2.85	3.5	8.5	8.95	9.4	87.2	87.38	87.6
11	T11	23.8	98.38	124.1	0.5	36.85	350.7	42.4	200.01	314.9	2.8	3.01	3.2	7.0	8.24	9.3	87.2	87.39	87.7
12	T12	35.5	40.48	47.2	1.2	1.53	1.7	47.0	54.15	63.6	2.5	2.76	3.1	8.2	8.40	8.6	87.0	87.28	87.5
13	T13	0.6	37.62	49.6	1.0	1.38	1.7	1.9	50.99	65.7	2.6	3.07	3.1	8.6	9.34	10.0	87.2	87.42	87.8
14	T14	0.8	11.82	59.2	1.1	1.10	1.1	2.8	16.93	82.0	2.0	2.04	2.2	6.1	6.38	6.5	86.7	86.76	87.0
15	T15	23.1	124.44	149.8	5.5	29.15	371.3	30.6	166.80	210.8	2.0	2.45	3.1	6.6	7.24	7.8	86.7	86.92	87.1
16	T16	106.1	140.67	156.0	5.4	9.66	16.4	137.9	190.69	230.4	2.0	2.27	2.6	5.9	6.71	7.8	86.7	86.90	87.0
17	T17	111.7	128.88	147.4	4.2	7.31	13.2	152.3	175.11	203.0	2.4	2.70	3.3	5.1	5.96	6.4	86.8	87.00	87.2
18	T18	106.7	124.78	134.1	13.5	21.57	56.6	134.1	163.72	190.1	2.0	2.08	2.3	4.7	5.03	5.5	87.2	87.43	87.6
19	T19	114.1	133.18	157.1	7.7	15.03	33.6	153.7	196.36	458.3	1.7	2.10	3.1	5.3	5.78	6.0	86.5	87.52	88.3
20	T20	108.6	129.08	144.4	8.0	12.54	24.3	142.1	174.41	197.0	1.9	2.13	2.4	10.1	10.21	10.3	87.0	87.66	88.6
21	T21	106.0	118.19	126.3	4.1	9.48	32.5	131.3	169.57	451.1	1.6	2.11	2.7	10.2	10.58	11.1	87.4	87.81	88.3
22	T22	105.3	121.81	137.7	5.4	10.07	20.3	133.6	156.01	189.0	1.5	1.74	2.1						
23	T23	96.4	109.44	124.9	4.6	7.65	20.4	123.4	143.45	174.1	1.6	1.93	2.8						
99	After	72.1	123.00	172.3	2.8	12.10	169.9	90.6	167.55	309.4	1.3	2.39	13.4						

		Lance Temperature (F)			Acivated Carbon (PPH)			Reagent B (PPH)			Prime Air (KPPH)			Steam from SHTR (KPPH)			Steam from SHTR (F)		
SERIES	TEST ID	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
-99	Before													0.0	55.62	62.7	364.4	515.08	603.9
0	Between	0.0	79.44	100.0	0.0	6.62	13.5	0.0	134.78	376.0	35.3	63.25	96.9	46.2	56.19	59.3	512.6	523.90	526.0
1	T1													33.0	55.68	60.0	503.6	522.50	527.1
2	T2													53.8	56.16	56.9	522.8	524.49	525.2
3	T3													43.4	54.74	57.1	510.3	523.14	525.6
4	T4													56.0	56.52	56.9	523.8	524.46	525.0
5	T5													55.1	56.42	57.1	521.8	524.38	525.4
6	T6	0.0	0.00	0.0	0.0	0.55	5.8	0.0	0.00	0.0	40.5	47.59	57.8	56.2	56.49	56.8	523.4	524.11	524.7
7	T7	0.0	39.81	68.0	0.0	0.00	0.0	0.0	0.00	0.0	43.8	51.36	60.8	56.1	56.56	57.5	518.1	523.86	525.0
8	T8	70.0	72.23	73.0	13.4	13.47	13.5	133.5	150.16	155.2	41.7	50.01	71.3	54.9	56.40	57.1	514.3	522.12	524.3
9	T9	73.0	73.00	73.0	11.6	13.36	13.5	132.8	149.30	153.7	34.5	53.90	71.5	55.4	56.77	59.2	524.0	525.04	526.7
10	T10	88.0	92.24	95.0	13.4	13.47	13.5	136.4	150.78	154.9	48.0	58.34	73.3	56.0	56.47	57.2	523.4	523.86	524.5
11	T11	84.0	87.67	92.0	13.4	15.71	49.0	133.5	150.32	156.2	44.8	64.39	72.8	54.3	56.37	58.2	516.9	523.79	524.8
12	T12	88.0	88.65	90.0	0.0	0.00	0.0	135.0	150.60	154.8	40.4	56.22	74.6	55.8	56.45	57.2	523.7	524.38	525.4
13	T13	90.0	93.92	97.0	0.0	0.00	0.0	135.6	149.71	154.2	36.2	56.75	70.4	55.9	56.59	59.0	524.5	525.05	526.6
14	T14	81.0	81.78	82.0	13.5	13.50	13.5	138.6	150.23	154.9	48.4	58.70	76.0	53.6	55.95	57.5	513.0	520.13	524.0
15	T15	82.0	83.78	85.0	13.4	13.48	13.5	130.3	149.56	156.2	39.0	52.28	68.2	55.7	56.56	57.7	524.2	524.72	525.4
16	T16	79.0	80.87	81.0	9.9	9.90	9.9	134.6	150.01	155.1	40.0	64.86	85.7	55.4	56.43	57.4	521.0	524.61	525.8
17	T17	79.0	79.85	82.0	0.0	9.50	9.9	133.0	149.93	156.9	36.5	46.05	72.9	56.2	56.69	57.7	522.4	525.26	526.4
18	T18	75.2	76.73	79.0	0.0	0.00	0.0	130.4	150.14	156.8	53.8	63.07	72.1	55.2	56.35	56.8	521.7	524.32	525.1
19	T19	79.0	81.73	82.0	0.0	0.00	0.0	126.6	150.14	159.1	43.7	64.11	105.1	22.1	52.91	57.1	500.5	521.91	524.9
20	T20	100.0	100.00	100.0	6.4	9.61	9.9	134.5	149.27	154.7	51.6	69.93	83.5	54.2	55.80	56.9	522.2	523.28	524.4
21	T21	100.0	100.00	100.0	9.9	9.90	9.9	127.3	150.00	157.0	45.1	64.11	82.0	24.3	53.51	57.2	500.1	521.70	524.9
22	T22													53.1	56.31	57.1	521.3	523.74	524.5
23	T23													48.8	56.09	57.5	514.5	523.80	525.1
99	After													41.4	55.93	58.9	509.0	523.86	526.6

		SHTR Outlet (F)			BFW to Econ (KPPH)			BFW Temperature (F)			FD Grate NONE			Furnace Pressure "H2O			FG from Precip "H2O		
SERIES	TEST ID	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	aximu
-99	Before	480.2	491.15	532.6	0.0	55.34	61.2	173.7	254.82	257.7	3.0	3.76	7.0	-1.2	-0.49	-0.1	-7.1	-2.79	0.0
0	Between	489.0	491.18	494.0	43.0	55.80	59.7	252.2	255.41	256.5	1.0	3.90	6.6	-1.0	-0.47	0.1	-10.7	-5.84	-0.2
1	T1	490.2	491.67	492.8	33.8	55.35	60.2	255.3	255.63	256.2	3.0	4.36	6.9	-0.7	-0.51	-0.4	-1.9	-1.50	-1.2
2	T2	491.0	491.41	491.6	49.8	55.78	57.7	254.7	255.30	255.7	2.5	4.19	7.0	-0.5	-0.50	-0.5	-1.7	-1.42	-1.0
3	T3	490.4	491.10	491.5	42.8	54.32	58.6	254.9	255.06	255.2	4.0	4.85	7.0	-0.9	-0.56	-0.5	-1.7	-1.35	-1.2
4	T4	491.2	491.40	491.5	55.3	56.21	56.9	255.2	255.23	255.4	3.0	3.52	4.9	-0.5	-0.50	-0.5	-1.7	-1.46	-1.3
5	T5	490.3	490.95	491.7	53.8	56.11	57.5	254.7	255.13	255.4	4.0	4.13	5.0	-0.5	-0.49	-0.4	-1.8	-1.44	-1.2
6	T6	490.6	491.42	491.5	55.3	56.08	56.7	255.4	255.64	255.8	3.0	3.26	5.0	-0.5	-0.50	-0.5	-1.5	-1.35	-1.1
7	T7	489.4	490.77	491.5	54.5	56.16	57.2	255.5	255.60	256.0	3.0	3.00	3.0	-0.5	-0.50	-0.5	-1.5	-1.28	-1.0
8	T8	489.6	490.96	491.6	53.3	55.78	57.9	255.3	255.47	255.8	3.0	3.34	4.0	-0.5	-0.50	-0.5	-0.2	0.05	0.1
9	T9	490.0	490.08	490.3	54.3	56.40	58.9	255.5	255.55	255.6	3.0	3.81	5.0	-0.5	-0.50	-0.5	-6.8	-2.06	0.1
10	T10	492.3	492.72	492.9	54.9	56.09	57.0	255.4	255.52	255.6	2.1	2.92	3.0	-0.6	-0.60	-0.6	-6.9	-6.36	-5.9
11	T11	490.7	491.68	492.4	53.7	55.91	58.0	255.3	255.39	255.6	3.0	3.00	3.0	-1.1	-0.63	-0.6	-6.9	-6.37	-5.6
12	T12	491.3	491.45	491.5	54.0	55.98	58.3	255.6	255.75	255.8	4.0	4.34	5.0	-0.6	-0.60	-0.6	-7.3	-6.52	-5.8
13	T13	490.7	491.26	491.5	55.3	56.18	58.5	255.5	255.61	255.7	4.0	4.00	4.0	-0.6	-0.60	-0.6	-7.4	-6.86	-5.9
14	T14	489.6	490.72	491.5	52.6	55.20	56.7	255.8	256.35	256.7	4.5	4.94	5.0	-0.6	-0.59	-0.5	-7.9	-7.04	-6.4
15	T15	490.0	490.94	491.5	54.6	56.03	56.9	254.8	255.44	255.8	4.0	4.95	5.0	-0.5	-0.50	-0.5	-8.6	-7.31	-5.9
16	T16	489.8	490.34	491.1	54.0	56.06	57.7	254.9	255.19	255.5	5.0	5.00	5.0	-0.5	-0.38	-0.2	-9.5	-8.93	-7.4
17	T17	490.0	490.05	491.2	54.3	56.32	57.4	254.9	255.07	255.2	5.0	5.00	5.0	-0.5	-0.46	-0.1	-9.7	-8.79	-8.2
18	T18	490.4	490.81	491.3	54.6	55.91	56.9	255.3	255.35	255.4	4.0	4.08	4.9	-0.5	-0.46	-0.3	-9.4	-8.26	-7.2
19	T19	488.4	490.24	494.4	26.9	52.51	58.3	255.3	255.49	256.1	3.0	4.68	5.0	-0.5	-0.40	0.1	-9.8	-8.47	-6.6
20	T20	490.9	491.36	491.5	53.1	55.47	56.7	255.6	255.63	255.7	4.0	4.01	4.1	-0.4	-0.26	-0.1	-10.7	-10.52	-10.1
21	T21	488.6	490.58	495.2	27.0	53.11	58.2	255.3	255.59	255.7	3.0	4.03	5.9	-0.5	-0.29	-0.1	-10.7	-10.21	-8.5
22	T22	490.0	490.60	491.5	51.8	55.78	56.9	255.2	255.38	255.5	3.0	3.00	3.0	-0.4	-0.24	0.0	-10.7	-10.38	-9.6
23	T23	489.7	489.99	490.3	46.1	55.49	57.2	255.2	255.33	255.5	3.0	3.32	4.3	-0.5	-0.27	0.1	-10.7	-10.50	-10.0
99	After	487.1	489.13	492.1	40.8	56.23	60.0	253.5	255.27	256.0	2.0	3.81	5.2	-1.2	-0.36	0.2	-11.4	-9.25	-5.6

		Boiler First Pass (F)			Boilere Second Pass (F)			FG to SHTR (F)			FG from SHTR (F)			FG to Econ (F)			FG to Precip (F)		
SERIES	TEST ID	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
-99	Before	1474.6	1554.89	1653.3	1305.9	1340.25	1366.5	0.4	1401.06	2943.9	1147.5	1178.92	1217.0	538.3	635.64	688.2	417.0	434.50	451.7
0	Between	1332.6	1597.46	1775.1	1320.9	1393.09	1444.2	1161.6	1332.11	1397.0	1125.0	1233.16	1288.1	315.2	657.34	721.8	284.7	349.67	450.0
1	T1	1079.0	1544.18	1679.7	1210.2	1334.86	1372.8	931.0	1284.65	1347.7	990.8	1185.21	1228.7	615.6	674.51	690.0	424.5	435.57	451.1
2	T2																		
3	T3																		
4	T4																		
5	T5																		
6	T6	1570.9	1606.42	1628.5	1374.5	1378.28	1381.0	1309.1	1317.47	1323.6	1212.8	1218.24	1222.3	662.8	670.55	675.8	420.0	426.46	430.5
7	T7	1560.8	1591.01	1607.3	1378.8	1383.91	1392.3	1315.7	1325.54	1336.3	1217.6	1225.55	1234.6	660.1	670.75	680.1	369.0	400.28	436.0
8	T8	1464.9	1587.12	1610.3	1382.5	1396.67	1409.2	1307.1	1336.65	1353.5	1212.3	1231.14	1242.2	657.8	668.43	677.7	350.7	364.48	378.6
9	T9	1531.7	1569.37	1669.8	1385.3	1398.31	1409.8	1319.3	1337.36	1366.7	1224.2	1235.38	1252.1	667.8	677.57	689.1	363.2	374.59	389.6
10	T10	1553.1	1585.16	1605.9	1357.9	1374.81	1380.7	1296.6	1310.52	1318.3	1210.4	1215.45	1220.3	665.7	669.54	674.0	283.3	292.30	310.1
11	T11	1478.8	1552.47	1575.0	1372.6	1381.44	1386.7	1280.6	1323.59	1348.2	1204.5	1218.97	1226.8	652.1	666.11	674.4	289.0	300.89	312.4
12	T12	1579.7	1616.54	1647.8	1362.7	1381.52	1390.7	1318.0	1333.33	1342.0	1217.8	1227.73	1232.9	650.3	659.29	668.8	294.1	304.18	314.0
13	T13	1574.6	1603.40	1683.1	1392.4	1397.66	1408.7	1333.0	1342.38	1374.8	1232.6	1238.82	1255.1	652.7	663.24	675.5	297.7	305.32	314.8
14	T14	1510.6	1580.81	1604.8	1392.8	1402.14	1405.1	1297.6	1330.65	1352.1	1221.1	1233.25	1244.7	627.9	640.57	648.6	341.6	352.59	368.3
15	T15	1552.8	1591.41	1672.5	1406.0	1416.08	1419.5	1344.3	1351.60	1362.9	1247.2	1252.48	1261.1	639.9	650.20	669.4	340.0	357.78	369.6
16	T16	1555.3	1605.56	1657.9	1404.8	1410.16	1415.1	1332.5	1347.75	1364.7	1237.2	1250.92	1255.8	644.3	658.33	669.1	341.2	354.53	362.3
17	T17	1599.1	1624.29	1669.8	1419.0	1428.04	1433.4	1336.5	1363.34	1377.6	1244.9	1261.20	1266.1	645.7	652.65	661.4	348.5	355.80	365.1
18	T18	1588.9	1639.15	1694.1	1404.3	1409.34	1413.2	1316.4	1334.92	1344.4	1230.6	1241.19	1248.3	659.6	667.25	676.1	343.2	354.35	366.0
19	T19	978.6	1564.62	1726.8	1233.9	1363.57	1415.9	879.8	1295.83	1358.3	966.9	1205.98	1254.6	563.2	655.93	679.1	335.0	355.66	365.2
20	T20	1570.5	1622.91	1686.0	1404.8	1410.26	1412.9	1329.8	1346.13	1372.1	1232.3	1245.47	1255.6	684.3	691.28	698.7	315.2	323.03	327.7
21	T21	1048.4	1582.95	1690.0	1264.1	1386.22	1422.2	900.5	1324.40	1366.3	1004.1	1226.72	1262.8	600.2	673.39	697.7	308.3	323.71	331.6
22	T22	1585.0	1652.28	1696.2	1422.5	1426.87	1430.8	1345.8	1373.28	1389.9	1248.3	1265.07	1273.3	635.8	657.59	678.0	321.4	339.36	390.1
23	T23	1475.0	1653.65	1688.6	1399.1	1427.19	1444.2	1282.5	1378.83	1398.8	1202.5	1269.33	1291.1	630.0	649.71	675.2	332.0	339.87	345.3
99	After	1323.9	1639.07	1786.3	1298.7	1433.41	1471.6	1148.6	1366.78	1432.9	1123.5	1242.11	1297.1	291.5	614.23	662.7	232.7	373.95	434.2

		Precip Out (F)			Ambient Humidity (PCT)			Ambient Temperature (F)		
SERIES	TEST ID	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
-99	Before	409.7	424.60	439.1				29.1	35.62	45.4
0	Between	293.2	348.32	440.0	17.5	27.78	60.4	29.0	41.50	57.1
1	T1	420.4	428.29	440.1				41.7	54.17	62.6
2	T2									
3	T3									
4	T4									
5	T5									
6	T6	413.0	418.35	421.5	19.6	22.49	25.8	41.0	49.23	54.6
7	T7	363.2	392.46	421.4	19.0	20.73	23.0	44.0	50.61	56.1
8	T8	341.1	351.32	358.4	18.0	20.94	24.3	41.5	50.06	58.1
9	T9	326.0	384.84	690.1	18.3	20.23	22.3	47.1	51.77	56.9
10	T10	290.6	301.67	327.6	22.4	24.03	25.1	43.3	45.65	49.1
11	T11	298.9	306.00	316.1	19.5	20.56	22.5	44.3	50.81	54.2
12	T12	300.6	307.01	314.7	20.2	22.11	23.4	42.8	46.90	52.0
13	T13	303.7	309.84	316.6	18.6	19.15	20.6	49.5	54.18	56.0
14	T14	346.3	352.25	360.3	19.5	20.84	22.2	44.6	48.73	52.7
15	T15	340.3	356.11	365.8	16.9	17.85	19.1	53.0	57.32	60.7
16	T16	342.0	353.06	358.3	16.5	18.26	20.1	48.7	55.18	61.5
17	T17	345.2	351.91	356.9	15.6	16.60	17.9	56.0	60.83	64.3
18	T18	341.8	348.88	358.5	25.5	27.35	28.7	39.0	39.40	40.8
19	T19	340.9	353.42	361.2	23.0	24.83	33.4	32.6	39.02	41.9
20	T20	314.1	320.31	324.5	29.2	31.90	35.0	31.0	32.86	35.7
21	T21	311.7	321.47	327.4	26.0	29.67	36.6	30.9	35.55	38.4
22	T22	320.7	334.92	363.1				33.5	35.27	37.8
23	T23	328.1	334.92	339.1				39.5	41.48	43.6
99	After	253.8	368.00	422.3				32.6	48.68	64.0

DATA VARIABLES USED IN APPENDIX B

TTHROAT	Flue gas temperature in the furnace throat -- °F
BOILERO2	*In situ* oxygen measured at the economizer inlet -- $\%_{wet}$
STACKO2	Oxygen measured at the stack -- $\%_{dry}$
CORCO	Stack CO -- ppm_{dv} @ 7% O_2
CORSO2	Stack SO_2 -- ppm_{dv} @ 7% O_2
CORNOX	Stack NO_x -- ppm_{dv} @ 7% O_2
OPACITY	Stack opacity -- percent
GPMH2O	Feed water flow -- gallons per minute
PSPRYAIR	Atomizing air pressure -- psig
TH2OSPRY	Atomizer water temperature -- °F
LPHPAC	PAC addition rate -- lb/h
LPHTRONB	Trona injection rate -- lb/h
LPHPA	Primary air flow rate -- lb/h
LPHSTM	Steam raising rate -- lb/h
PSTM	Steam pressure (superheater outlet) -- psig
TSTM	Steam temperature (superheater outlet) -- °F
LPHBFW	Boiler feed water flow -- lb/h
TBFW	Boiler feed water temperature -- °F
RAMCYTM	Dwell between ram cycles -- min
GRATECYC	Grate cycles between ram cycles -- number
PFURN	Furnace pressure -- inches H_2O
PESP	ESP pressure -- inches H_2O
T1STPS	First furnace pass temperature -- °F
T2NDPS	Second furnace pass temperature -- °F
TSHIN	Superheater inlet gas temperature -- °F
TSHOUT	Superheater outlet gas temperature -- °F
TECONIN	Economizer inlet gas temperature -- °F
TESPIN	ESP inlet (economizer outlet) gas temperature -- °F
TESPOUT	ESP outlet gas temperature -- °F
TAMB	Ambient temperature -- °F
RHAMB	Ambient relative humidity -- %

APPENDIX C

SYSTEM OPERATING EXPERIENCE

APPENDIX C

SYSTEM OPERATING EXPERIENCE

Installation of the portable PAC dosing system, complete with the pin-belt carbon block conveyor and transition hopper were accomplished by the plant personnel. The initial carbon bag was put into service by the supplier's representative and operation commenced with little difficulty. The discharge from the transition chute was inspected to verify that PAC was being added to the system. The Cambelt conveyor did not discharge a continuous stream of PAC; rather, surging increments were discharged on a regular basis that coincided with either pin-flight separations or screw feeder speed.

The system calibration was checked by running the feeder and conveyor for a finite time and collecting all discharged PAC. This material was weighed and the calibration settings confirmed.

The flow of PAC to the trona transfer system was initiated on November 18, 1995 after testing was completed for that day. Testing was completed on November 19, 1995 and routine inspections of the PAC discharge during testing showed flow to be satisfactory. At the end of the tests, the system was shut down until November 20, 1995 at 2130 hours. Inspection the following morning showed PAC to be flowing properly. After testing was completed on November 21, 1995, the bag was changed and flow was re-established. At 2100 hours, an inspection indicated all systems were operating satisfactorily.

On the morning of November 22, 1995, it was observed that the trona and the PAC were not feeding. Inspection of the operator's log from the night before found repeated trona feed problems leading to the system being out-of-commission for 2 hours during the night. After identifying the problem in the morning, the PAC feed system was shut-off and the trona injection system inspected. It was discovered that at some time during the night, the injection point for trona had been switched from the lower point (below the economizer) to a point down stream of the economizer and the water spray injection system. That lance was totally plugged with wetted and hardened materials so the system could not feed. The injection point was returned to the correct location and the systems were restarted.

At about 1330 hours on November 22, the PAC system alarm actuated. The snout was very flexible. Physical probing revealed an empty space above the snout suggesting that the system had developed a "rat-

hole". Flow was restarted at 1345 hours. A readout error on the DCS prompted reinitiating of the feeder operation at 1350. Testing resumed with the afternoon test at 1410 hours. Subsequent inspections in the afternoon indicated PAC flow was satisfactory.

On November 23, 1995, the PAC system was started at 1900 hours for overnight system stabilization. At 2115 hours, the system was in alarm. The bag appeared to have developed another "rat-hole". While this was rectified, the next morning the operators reported that the system had been in alarm on and off all night. The operators noted that the system would clear the alarms by itself. At 0630 hours on November 24, the throat of the spout was not full and the center was empty again. By 0800, the system was operating satisfactorily. Operation of the PAC system continued throughout the day without notable problems until 1540 hours when the system was again in alarm and resetting itself. Elevating the partially empty bag seemed to allow better flow.

The PAC was being emitted in more pronounced slugs than previously. This was causing the sorbent feed system to occasionally overload and the PAC was spilling onto the reagent room floor. The transition was rapped sharply to alleviate the feed problem.

The PAC flow was adjusted to 15 pounds per hour at 1820 hours on November 24, and the system was left to run at 15 pounds per hour overnight to empty the bag. Operators reported that the alarms continued to occur overnight and cleared themselves; however, they decided to turn the carbon system off at 0600 hours on November 25. There was still PAC in the bag at 0650 hours so it was restarted and run until 0830 hours.

The PAC flow was re-established at 15 pounds per hour with a new bag at 0915 on November 25. Feeding was uneventful throughout the day and the feed was shut-off at 1915 hours.

15 pounds per hour of PAC flow was established at 1730 on November 26. Operators reported no particular problems with the system overnight; however, inspection at 0755 revealed carbon all over the reagent room floor. Closer inspection of the discharge revealed that the carbon was flowing uncontrollably. The system was shut-off and the Cambelt conveyor was stopped. Flow eventually stopped. The Cambelt conveyor was restarted and free-flow reoccurred. Repeated start-stop cycles were necessary to re-establish even flow. It appeared that the carbon in the bag and feed screw system had fluidized. When this hap-

pened, PAC flow could not be controlled. A check found the fluidizing air supply to be at 40 psi. The pressure was re-set to 23 psi. The supplier advised that they usually set the fluidizing air at 20 to 25 psi.

The system appeared to run satisfactorily for the rest of the day. The system was maintained at 15 pounds per hour until 0730 on November 28. While testing had officially finished at this time, it was decided to run the 2 bags of carbon left at the testing site through the PAC dosing system at a nominal feed rate to use the material and give plant personnel additional operating experience with the system. The bag was changed, but when the system was restarted, the screw feeder appeared to be laboring and the Cambelt conveyor would not start. Inspection revealed that the transition hopper at the Cambelt discharge was plugged. Work to clear the Cambelt conveyor casing and restore the system to operation was very messy.

It is speculated that the transition became plugged at some time overnight and when this happened, the balance of the system continued to operate until the Cambelt conveyor tripped on overload. This condition went unnoticed as there were no alarms and the screw feeder continued to force material into the discharge of the PAC feeder until no material was left. The weather was distinctly colder than previously and this could have affected material flow.

The water cooling system described in Section 2 includes the spray lance equipped with three Bete Model 5A bi-fluid nozzles and air and water supply systems feeding the lance. The fabrication of the lance was accomplished by plant maintenance staff. Insertion of the lance into the duct was relatively straightforward although it took considerable manual effort because the location did not lend itself to use of a hoist.

Both 85 psi air and water were supplied to the lance. The volume of air required, 150 scfm, was too large for the plant air system. An additional compressor was rented It was deemed impractical to install permanent piping for the air system just for the test. Two types of flexible hose were tried and three different clamp arrangements were used before a successful connection was made to the lance. The final installation used spiral wrapped Barracuda hose and bolted clamps to attach the hose to quick-disconnect fittings.

Water was supplied from the pumps that had been used for previous water spray cooling development at the facility. Fiber reinforced hose was used to connect the pump discharge to the lance. The water supply system included an air-operated plug valve to control water flow and manual shut-off valves around the pumps. The only major system limitation was the control characteristics of the modulating valve. Until the water pressure equalized that of the air, water did not flow. This limited the effective range of the plug

valve since it needed to be about 50% open before water flow would start. At operating conditions requiring minimal water addition, the limitations in the operating range led to increased control sensitivity. Incremental changes of 1 and 2% needed to maintain desired ESP temperature conditions required frequent operator intervention.

A nozzle was set-up in a test rig outside to view the spray pattern and the droplet size at flows and pressures below those used during plant testing. Even under these conditions, a very confined spray originated from the nozzle and was about 1 foot in diameter within 18" of the discharge. A fine mist was visible about 5 feet from the nozzle, where the plume was 2 feet in diameter. At 20 feet, the plume had spread to 3 to 5 feet in diameter, but the droplets were evaporating and the plume went to extinction.

Start-up procedures minimized the potential for steam formation in the lance. The lance was inserted into the duct and the air flow was established. Before the initial water connection was made, the water lines were purged. The water line was then connected to the lance and the water flow initiated. A setting of 55% on the valve initially provided 3.3 gpm flow to the lance. The flow was adjusted to 4.3 gpm to drop the ESP operating temperature to 350°F. The initial start-up occurred at 1600 hours on November 20 and operations were uneventful overnight and through the next day. Water flow was increased late in the day on November 21 and outlet temperatures as low as 290°F were recorded the next day with flows of 9.4 gpm.

Prior to testing on November 22, 1995, the system was inspected. The lance was pulled from the duct and the nozzles were replaced with new atomizers although no fouling was evident. During the inspection of the interior of the duct, a soft build-up of trona was noted on top of the economizer. The initial consensus was that this could have been the result of water impingement on the surface via recirculation and subsequent coating with the reagent; however, the significance of the operating staff changing the trona injection point during the night was overlooked. Because of the concern about potential build-up, it was decided that the orientation of the lance should be adjusted to make the spray direction more in the direction of the flow (from 10° above the centerline to 35° below the centerline). To accomplish this, the flange on which the lance was mounted was rotated one hole counterclockwise when it was re-installed. In all, the probe was out of the stack for less than 20 minutes, and temperatures were re-established in the test range by 0910 hours when testing started.

Inspection of the nozzles removed from the lance showed a white deposit on the interior Bete scroll and on the outer wall of the mixing chamber. The holes in the nozzle were clear. The deposits may have been flash deposits created when flow was initiated Throughout the course of the subsequent testing, the water flow rate required to maintain outlet gas temperature increased suggesting potential decreases in the heat transfer performance of the economizer. Inspection prior to power washing on November 29, 1995 showed deposits on various surfaces of the economizer, leading credence to this conclusion.

Inspection of the lance after seven days of operation showed the nozzles to still be functional, but the realignment had caused increased deposition on the washers and surrounding surfaces. Given that some of the observations of duct deposits suggested that surface impingement may have led to build-ups, the orientation of the lance was returned to the design configuration. An outage occurred on December 4, 1995 that was attributed to deposits sloughing back from the duct to the economizer and quenching was ceased.

By November 25, a water flow of 5.5 - 6.5 gpm was needed to maintain the desired 350°F gas temperature. On November 26, the system temperature would not come down as easily as it had earlier and the operator undertook a sootblow to clear the system. This re-established an appropriate temperature regime and temperature was maintained at 350°F using approximately 5.5 gpm of water.

On November 27, the water control valve was wide open and flow was approximately 10.1 gpm, but the planned temperature of 300°F could not be achieved. Discussions with operating personnel early in the morning revealed that sootblows occurred at 0300 hours and at 0700 hours. Every indication was that the system was beginning to plug and the operators suggested that they might need to power wash the system. Water temperature readings around the economizer were out-of-line with those on the A unit and it was strongly suspected that the area was were becoming plugged with reagent. This would cause channeling flow and less cooling. The inability to achieve low temperatures prompted a change in operation conditions for Day 11 to a temperature of 325°F.

On November 28, the valve was again at maximum opening, but the flow was slightly higher at 10.7 gpm. A malfunction in one of the facility's air compressors forced the cooling system off-line at 1004 to facilitate a cross connection to the cooling system compressor. The water flow was not shut-off for several minutes after the air flow was off. This may have exacerbated wetting problems in the duct where the spray was directed at the lower breaching wall. Flows were re-established at 1043, but maximum the water flow was only 9.8 gpm. The target temperature could not be achieved following this interruption, but testing pro-

ceeded at 335°F for the balance of the day. At 1852, the compressor was again taken out of service, but the water was shut-off first. The system was restarted later that evening, and on the following morning, the water flow was 12.4 gpm. Discussions with the operators noted that start-up was handled slightly differently this time. The flow valve was wide open and the pressure in the pump built up before the shut-off valve was opened. It is assumed that this might have cleaned any blockages out of the system.

During power washing of the unit on November 29, several observations were made. The side walls of the duct appeared to be coated with materials along the full height of the economizer. Furthermore, the downstream side of the economizer wall was covered with a deposit at several elevations. This deposit was thickest at the top of the economizer and also appeared to be thicker at positions across the width of the duct corresponding to the locations of the nozzles. This suggests that some water impingement may have been occurring on these surfaces. These deposits were relatively soft and easily removed suggesting that they had not been fully wetted.

On November 29, the lance was removed for inspection. The lance nozzles were covered with deposits, but the holes were still open. Given the observations of deposits in the system at this time, discussions continued with the operators about both the configuration and the orientation of the lance. It was decided that the location of the nozzles should be adjusted by bringing the outer nozzles closer to the middle of the duct. The lance orientation was also to returned to its original location. The consensus was that impingement likely occurred against the lower wall of the breaching between the economizer outlet and ESP inlet.

The system was power washed, but a second outage occurred on December 4 when the top of the economizer was again covered with deposits. At this time, speculation suggested that the operation of the sprays may have caused particulate matter to settle out onto the bottom of the breaching leading to the economizer. This material would not have been observed during the on-line cleaning of the system in November and could have slid down the duct floor to the top of the economizer. This mechanism suggests that an intercepting hopper could be used to remove material before it reached the economizer. Theoretical calculations indicate that gas velocities are reduced to 90 percent of design when the sprays are used. The sprays could also cause some particle agglomeration. Since larger agglomerated particles would settle faster and lower bulk gas velocities also reduce the particle size carried over between the economizer and ESP, even without wall wetting induced by misorienting the nozzles, an accumulation could have occurred. Vibrations could set the settled mass in motion and cause it to slough onto the economizer. In configurations like the DCERF, it is important to:

- locate the nozzles far enough in from the ends to prevent wall wetting due to recirculation and wandering flow induced by cooling the gas along the duct centerline;
- orient the nozzles slightly above the flow centerline—10° was used here; and
- install a hopper in the underside of the breaching to prevent sloughed sedimented particulates from plugging the economizer.

APPENDIX D

OTHER DSI/ESP EQUIPPED MWC EXPERIENCE

APPENDIX D

OTHER DSI/ESP EQUIPPED MWC EXPERIENCE

Availability of test results from European MWC facilities equipped with ESPs that use DSI was brought to our attention during the final review of this report. These results are summarized and references provided to help users of this report.

Sodium based reagent test results are available for at least the following facilities:

- Edegem (Antwerp) Belgium -- a 2 by 132 MWC facility with 5 second retention time tubular reactor, cyclone and ESP operating at 437°F,
- Reims, France, and
- Pontivy, France.

No descriptions of the two French facilities or their APCS were provided in the available report summaries. Testing program results principally include acid gas removal efficiency and dry reagent stoichiometric ratio. The stoichiometric ratio may be on a total acid gas basis (SO_2, HCl and HF) since one report indicates that all three pollutants were measured.

Figure D-1 is a plot of the Edegem sodium bicarbonate test results and calculated emissions limitations for this test[1]. The summary bulletin included a notation that two of the eleven sodium bicarbonate tests conducted in 1988 resulted in exceedances of the facility's 151 mg/dsm^3 @ 7% O_2 (0.066 gr/dsft^3 @ 7% O_2) particulate emission limitation. The stoichiometric addition rate being tested during the exceedances is not known.

HCl emissions control system efficiency test results for MWCs using trona are plotted in Figure D-2 along with the resulting calculated emissions limitations for each facility[2].

Laboratory testing indicates that trona and sodium bicarbonate exhibit generally similar emissions control performance[3]. This general similarity in behavior is supported by the results presented in Figures D-1 and D-2; both figures indicate that similar stoichiometric ratios are needed to provide reasonable assurance that a specified emissions limitation can be met. Those who wish to pursue increasing the stoichiometric ratio are cautioned to keep in mind that this action can significantly increase the particulate loading to the ESP and can alter the leaching characteristics of the residue.

Lime based sorbents were originally used at DCERF. The historical data for dry powdered hydrated lime injection provided in Table 3-2 are plotted along with calculated emissions limitations in Figure D-3. In the vicinity of the data centroid, the routinely expected removal efficiency is above 50 percent at ESP temperatures around 350°F. The calculated emission limitations have more uncertainty outside the data range (360-410°F ESP temperatures; 1.4-1.8 stoichiometric ratio). This is a natural consequence of the uncer-

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[1] _____, "Deacidification of refuse incineration flue gases with sodium bicarbonate", Bicarb•Bulletin, Church & Dwight Co., Inc., Princeton, NJ, undated.

[2] _____, "Solvay T-200 use in dry injection scrubbing for HCl removal", Central Study and Research Center, Solvay S. A., Dobasle, France, July 1993.

[3] _____, "CER* Development, Smoke Purification -- MIPEF Declorination test with Trona", Central Study and Research Center, Solvay S. A., Dobasle, France, July 1, 1993.

tainty which characterizes extrapolations. Figure D-3 is generally consistent with a prior analysis of some of the DCERF lime based DSI data[4]. Greater than 50 percent HCl removal at stoichiometric addition rates of 2.5:1 are reported, but particulate emissions were not simultaneously measured so compliance status is unknown.

Additional studies of dry lime injection at MWCs exist (see for example, reports of work at North Andover, MA[5] and Detroit, MI[6]). These and other similar reports should be considered as final, site-specific reagent selection and stoichiometry decisions are made.

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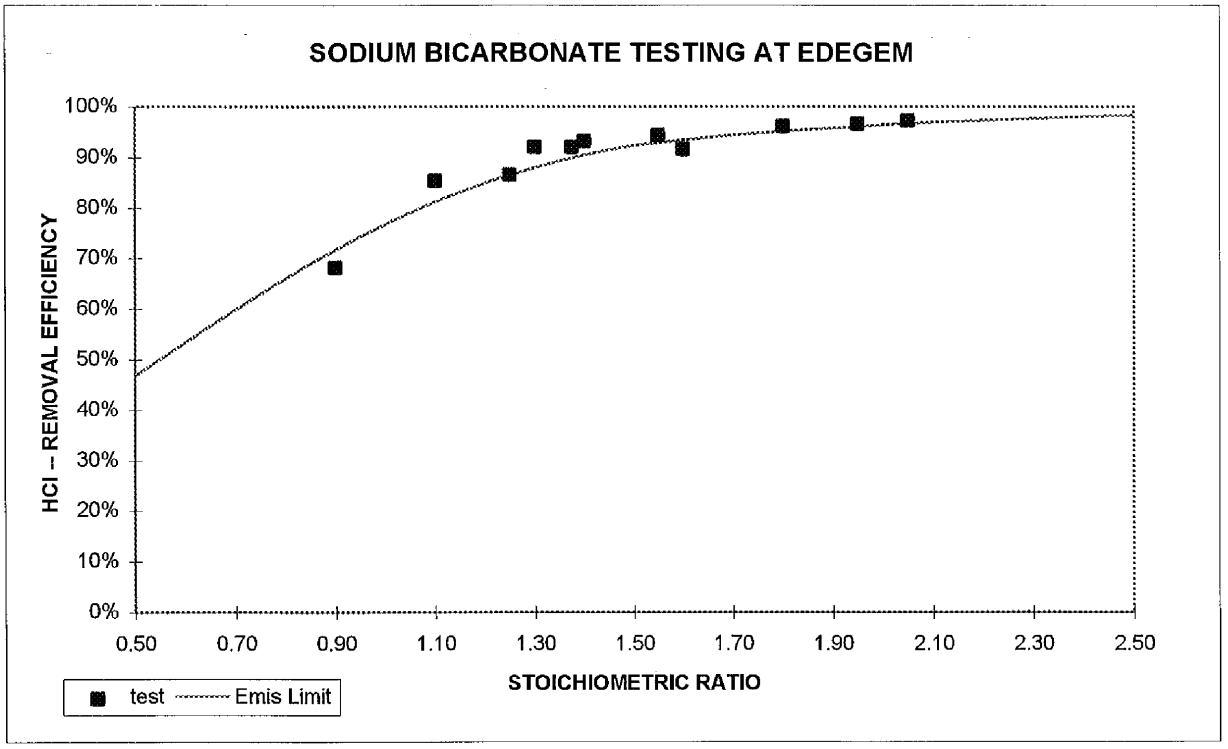
[4] Beckman, A. H. and D. R. Spohn, "Dry lime injection for acid gas control in municipal waste incinerators", Paper 89-23B.2, AWMA, 1989.

[5] Massachusetts Refusetech Inc., Draft Final Report -- Prototype demonstration of dual sorbent injection for acid gas control on municipal solid waste combustion units, NREL, Golden, CO, January, 1994.

[6] Zumda, J. T., "Retrofit for Cleaner Air", Solid Waste & Power, July/August 1992, pp. 12-22.

Figure D-1. HCl emissions at Edegem when using Sodium Bicarbonate.



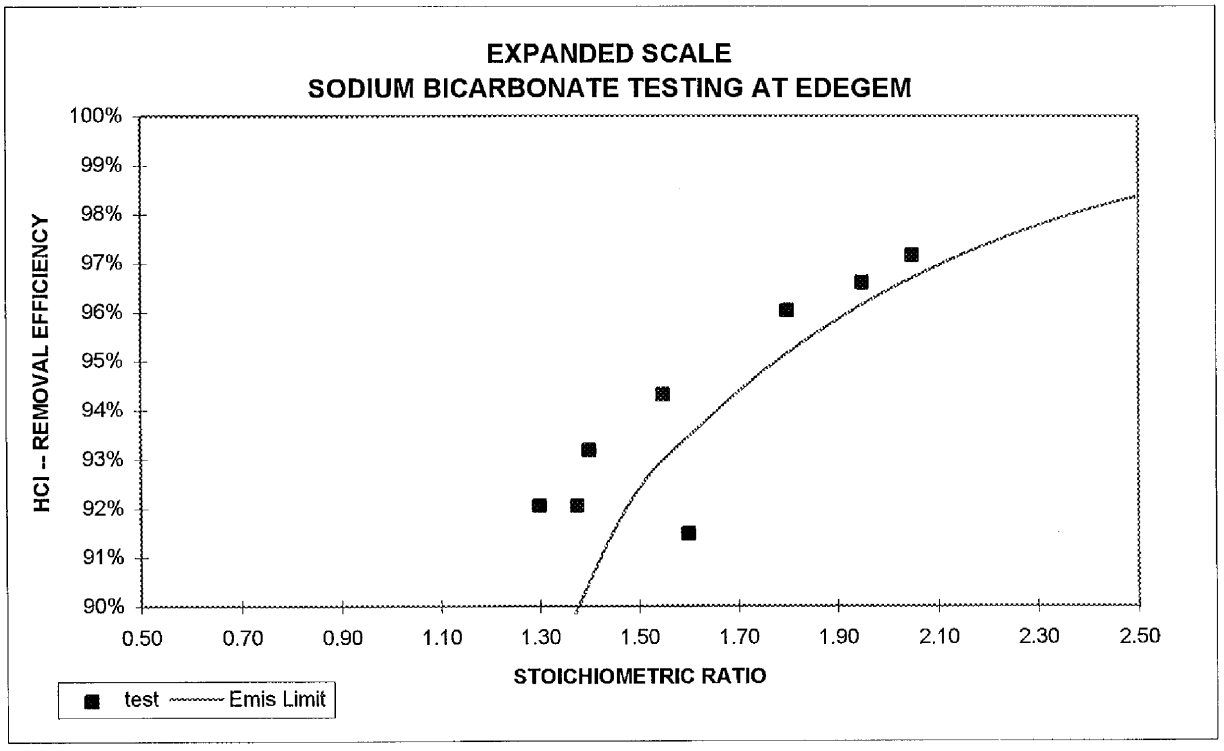
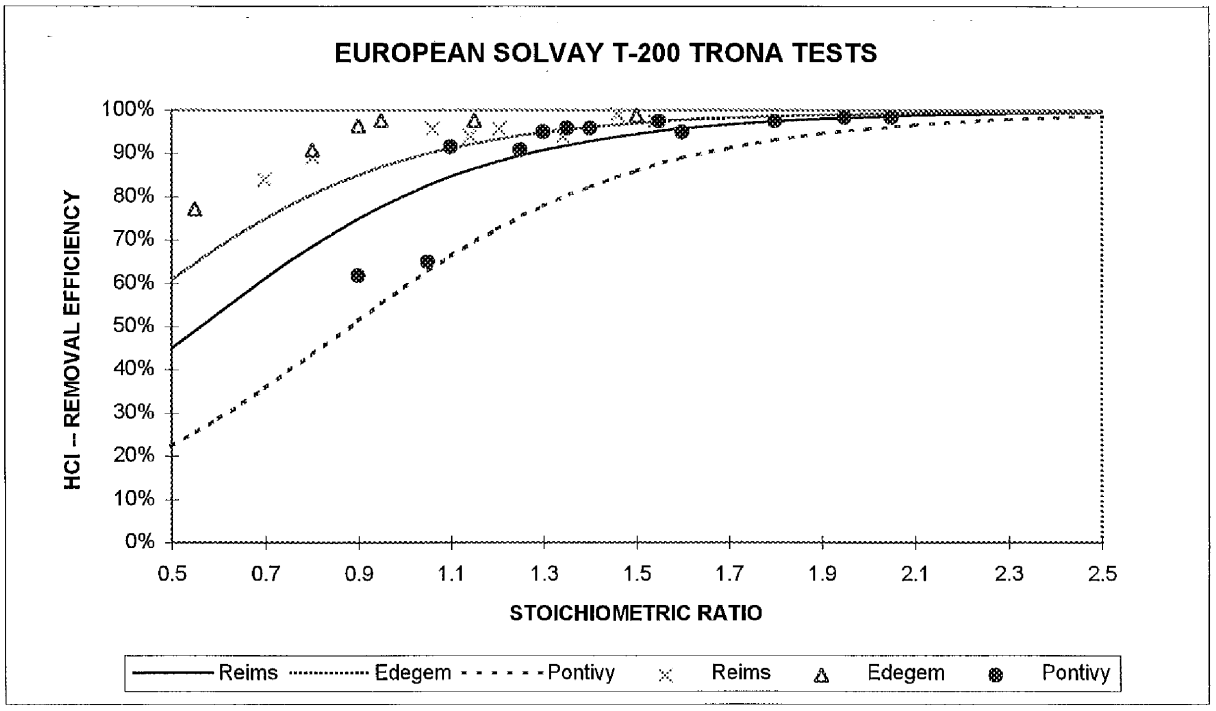
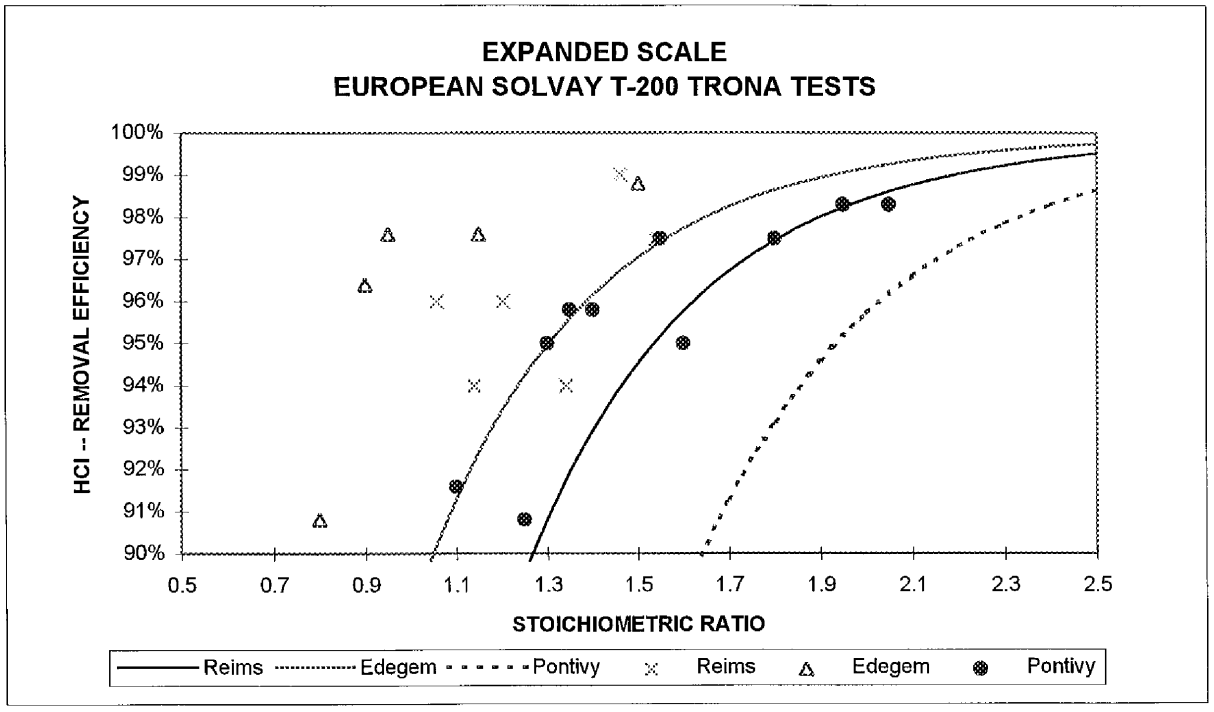


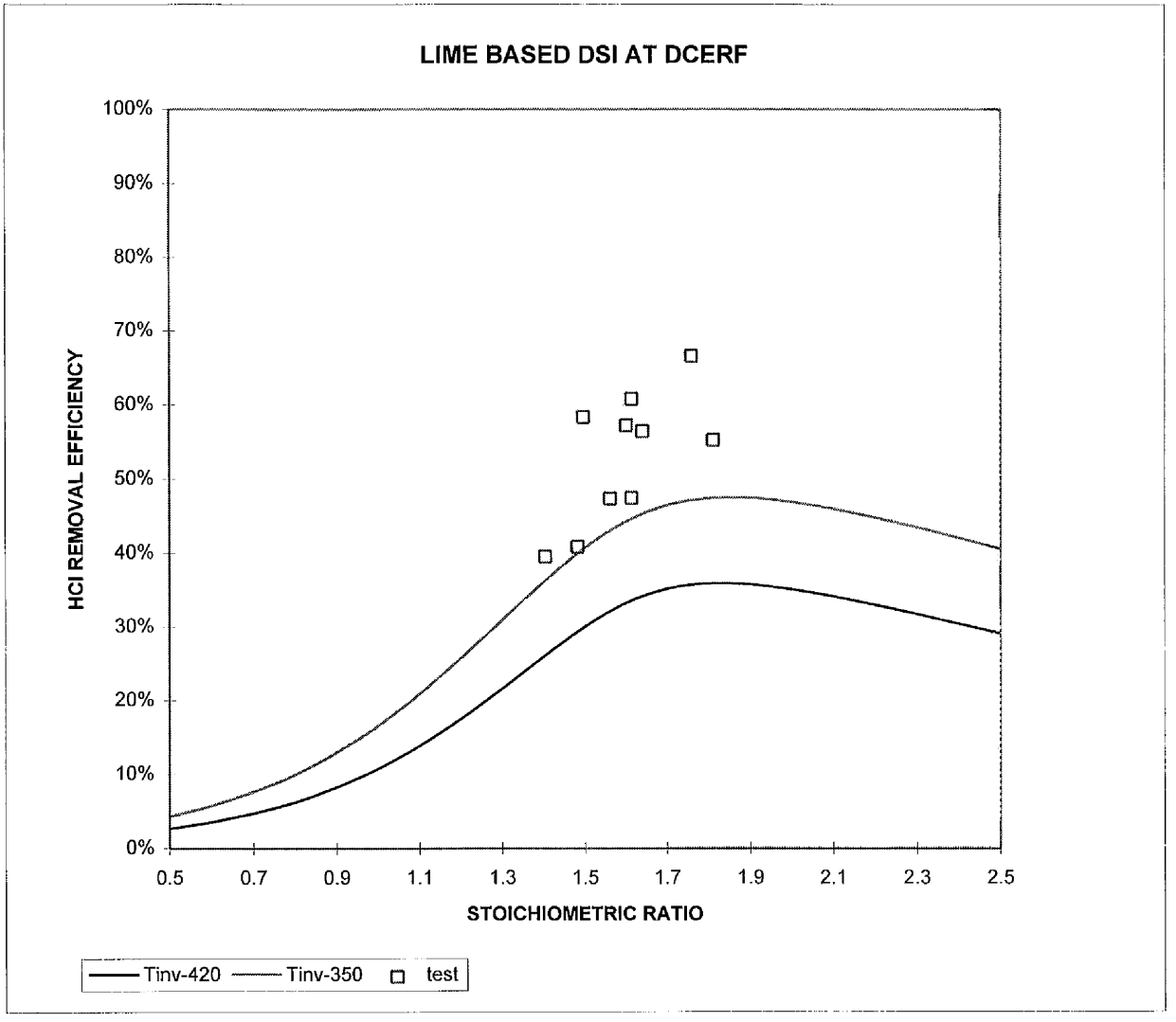
Figure D-2. Test data and calculated emissions limitations for three European MWCs using dry sorbent injection





notes: Edegem, Belgium MWC has a 5 second residence time tubular reactor and ESP; 0.067 gr/dsft^3 exceeded in two of the tests
Reims and Pontivy, France are MWCs of unknown character.

Figure D-3 Historical testing results using lime in the duct sorbent injection system at DCERF



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13. ABSTRACT (Maximum 200 words)
Many municipal waste combustion facilities are equipped with electrostatic precipitators (ESPs); few have acid gas control systems. A retrofit technology using water spray temperature reduction combined with dry acid gas control reagent and powdered activatedcarbon (PAC) injection was tested. 2000 mg/dsm^3 @ 7%O_2 (150 ib/hr) of trona (a natural sodium sesquicarbonate ore) injected through a rapid dispersion lance successfully controlled more than 50% of the acid gases. This should let facilities under 250 TPD meet the small plant guidelines for acid gas control. Various levels of PAC were injected along with the trona. 300 mg/dsm^3 @ 7% O_2 of PAC provides a comfortable margin between the emissions limitations achieved and both large and small plant regulatory guidelines for tetra-through octa-chlorinated dibenzo-p-dioxins and dibenzofurans and mercury, when ESP is operated below 350°F. Bi-fluid nozzles were used to spray finely atomized water between the economizer outlet and ESP inlet to maintain temperatures in the desired 300-350°F range. Particulate and metals emissios limitations were met by this 400 ft^2/1000acft^2 specific collector area (SCA)m 3-field ESP. Both the water sprays and PAC improved ESP performance. The proof-of-concept demonstration was successful.

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Municipal waste combustion, electrostatic precipitators, water spray, powdered activated carbon injection

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