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INNOVATIVE CLEAN COAL TECHNOLOGY (ICCT)

500 MW DEMONSTRATION OF ADVANCED WALL-FIRED COMBUSTION TECHNIQUES FOR THE REDUCTION OF NITROGEN OXIDE (NO_x) EMISSIONS FROM COAL-FIRED BOILERS

Technical Progress Report
Third Quarter 1995

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EXECUTIVE SUMMARY

This quarterly report discusses the technical progress of an Innovative Clean Coal Technology (ICCT) demonstration of advanced wall-fired combustion techniques for the reduction of nitrogen oxide (NO_x) emissions from coal-fired boilers. The project is being conducted at Georgia Power Company's Plant Hammond Unit 4 located near Rome, Georgia. The primary goal of this project is the characterization of the low NO_x combustion equipment through the collection and analysis of long-term emissions data. The project provides a stepwise evaluation of the following NO_x reduction technologies: Advanced overfire air (AOFA), Low NO_x burners (LNB), LNB with AOFA, and advanced digital controls and optimization strategies. The project has completed the baseline, AOFA, LNB, and LNB+AOFA test segments, fulfilling all testing originally proposed to DOE.

Phase 4 of the project, demonstration of advanced control/optimization methodologies for NO_x abatement, is now in progress. The methodology selected for demonstration at Hammond Unit 4 is the Generic NO_x Control Intelligent System (GNOCIS), which is being developed by a consortium consisting of the Electric Power Research Institute, PowerGen, Southern Company, Radian Corporation, U.K. Department of Trade and Industry, and U.S. Department of Energy. GNOCIS is a methodology that can result in improved boiler efficiency and reduced NO_x emissions from fossil fuel fired boilers. Using a numerical model of the combustion process, GNOCIS applies an optimizing procedure to identify the best set points for the plant on a continuous basis. GNOCIS is designed to operate in either advisory or supervisory modes. Prototype testing of GNOCIS is in progress at Alabama Power's Gaston Unit 4 and PowerGen's Kingsnorth Unit 1. The first commercial demonstration of GNOCIS will be at Hammond 4.

During third quarter 1995, prototypes of GNOCIS continue to be tested at Alabama Power Company's Gaston Unit 4 and PowerGen's Kingsnorth Unit 1. Progress continued to be made on the installation of GNOCIS at Hammond 4 and modifications necessary for open- or closed-loop operation are virtually complete. Delays in delivery of the GNOCIS software package and unit unavailability have adversely impacted the demonstration schedule. Process data continues to be collected for use in model development. Although it is believed a suitable model has been created, refinements are continuing to be made in an effort to improve the robustness of the model prior to testing on the unit. The unit is currently off-line due to low generation demand. Upon resumption of consistent unit operation, approximately two months of GNOCIS testing will be conducted. Short-term, diagnostic tests were conducted during August 1995. The primary purpose of these tests were to determine the performance characteristics of the three on-line carbon-in-ash monitors installed on this unit. Further testing of these monitors is planned following resumption of unit operation. The draft Public Design Report was issued during September and is undergoing review by all project participants. The project is now scheduled for completion by December 31, 1995, however to accommodate delays associated with Phase 4, a project extension has been requested.

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acfm	actual cubic feet per minute
AMIS	All mills in service
AOFA	Advanced Overfire Air
ASME	American Society of Mechanical Engineers
C	carbon
CAA(A)	Clean Air Act (Amendments)
CEM	Continuous emissions monitor
CFSF	Controlled Flow/Split Flame
Cl	chlorine
CO	carbon monoxide
DAS	data acquisition system
DCS	digital control system
DOE	U.S. Department of Energy
ECEM	extractive CEM
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ETEC	Energy Technology Consultants
F	Fahrenheit
FC	fixed carbon
FWEC	Foster Wheeler Energy Corporation
Flame	Flame Refractories
GPC	Georgia Power Company
H	hydrogen
HHV	higher heating value
HVT	High velocity thermocouple
ICCT	Innovative Clean Coal Technology
KPPH	kilo pounds per hour
lb(s)	pound(s)
LNB	low NO_x burner
LOI	loss on ignition
(M)Btu	(million) British thermal unit
MOOS	Mills out of service
MW	megawatt
N	nitrogen
NO_x	nitrogen oxides
NSPS	New Source Performance Standards
O, O_2	oxygen
OFA	overfire air
PA	primary air
psig	pounds per square inch gauge
PTC	Performance Test Codes
RSD	relative standard deviation
S	sulfur
SCA	specific collection area
SCS	Southern Company Services
SO_2	sulfur dioxide
SoRI	Southern Research Institute
Spectrum	Spectrum Systems Inc.
THC	total hydrocarbons
UARG	Utility Air Regulatory Group
VM	volatile matter

1. INTRODUCTION

This document discusses the technical progress of a U. S. Department of Energy (DOE) Innovative Clean Coal Technology (ICCT) Project demonstrating advanced wall-fired combustion techniques for the reduction of nitrogen oxide (NO_x) emissions from coal-fired boilers. The project is being conducted at Georgia Power Company's Plant Hammond Unit 4 (500 MW) near Rome, Georgia.

The project is being managed by Southern Company Services, Inc. (SCS) on behalf of the project co-funders: Southern Company, U. S. Department of Energy (DOE), and Electric Power Research Institute. SCS is a subsidiary of the Southern Company that provides engineering, research, and financial services to other Southern Company subsidiaries.

The Clean Coal Technology Program is a jointly funded effort between government and industry to move the most promising advanced coal-based technologies from the research and development stage to the commercial marketplace. The Clean Coal effort sponsors projects that are different from traditional research and development programs sponsored by the DOE. Traditional projects focus on long-range, high-risk technologies with the DOE providing the majority of the funding. In contrast, the goal of the Clean Coal Program is to demonstrate commercially feasible, advanced coal-based technologies that have already reached the "proof of concept" stage. As a result, the Clean Coal Projects are jointly funded endeavors between the government and the private sector that are conducted as Cooperative Agreements in which the industrial participant contributes at least fifty percent of the total project cost.

The primary objective of the Plant Hammond demonstration is to determine the long-term effects of commercially available wall-fired low NO_x combustion technologies on NO_x emissions and boiler performance. Short-term tests of each technology are also being performed to provide engineering information about emissions and performance trends. Specifically, the objectives of the projects are:

1. Demonstrate in a logical stepwise fashion the short-term NO_x reduction capabilities of the following advanced low NO_x combustion technologies:

    - ◊ Advanced overfire air (AOFA)
    - ◊ Low NO_x burners (LNB)
    - ◊ LNB with AOFA
    - ◊ Advanced Digital Controls and Optimization Strategies

2. Determine the dynamic, long-term emissions characteristics of each of these combustion NO_x reduction methods using sophisticated statistical techniques.

3. Evaluate the cost effectiveness of the low NO_x combustion techniques tested.

4. Determine the effects on other combustion parameters (e.g., CO production, carbon carryover, particulate characteristics) of applying the above NO_x reduction methods.

2. PROJECT DESCRIPTION

2.1. Test Program Methodology

To accomplish the project objectives, a Statement of Work (SOW) was developed which included the Work Breakdown Structure (WBS) found in Table 1. The WBS is designed around a chronological flow of the project. The chronology requires design, construction, and operation activities in each of the first three phases following project award.

Table 1: Work Breakdown Structure

Phase	Task	Description	Date
0	0	Phase 0 Pre-Award Negotiations	
1	1	Phase 1 Baseline Characterization	
	1.1	Project Management and Reporting	8/89 - 4/90
	1.2	Site Preparation	8/89 - 10/89
	1.3	Flow Modeling	9/89 - 6/90
	1.4	Instrumentation	9/89 - 10/89
	1.5	Baseline Testing	11/89 - 4/90
2	2	Phase 2 Advanced Overfire Air Retrofit	
	2.1	Project Management and Reporting	4/90 - 3/91
	2.2	AOFA Design and Retrofit	4/90 - 5/90
	2.3	AOFA Testing	6/90 - 3/91
3	3	Phase 3 Low NO_x Burner Retrofit	
	3.1	Project Management and Reporting	3/91 - 8/93
	3.2	LNB Design and Retrofit	4/91 - 5/91
	3.3	LNB Testing with and without AOFA	5/91 - 8/93
4*	4*	Advanced Low NO_x Digital Control System*	8/93 - 10/95*
5*	5*	Final Reporting and Disposition	
	5.1	Project Management and Reporting	9/95 - 12/95*
	5.2	Disposition of Hardware	12/95*

*Schedule being revised to reflect project delays.

The stepwise approach to evaluating the NO_x control technologies requires that three plant outages be used to successively install: (1) the test instrumentation, (2) the AOFA system, and (3) the LNBs. These outages were scheduled to coincide with existing plant maintenance outages in the fall of 1989, spring of 1990, and spring of 1991. The planned retrofit progression has allowed for an evaluation of the AOFA system while operating with the existing pre-retrofit burners. As shown in Figure 1, the AOFA air supply is separately ducted from the existing forced draft secondary air system. Backpressure dampers are provided on the secondary air ducts to allow for the introduction of greater quantities of higher pressure overfire air into the boiler. The burners are designed to be plug-in replacements for the existing circular burners.

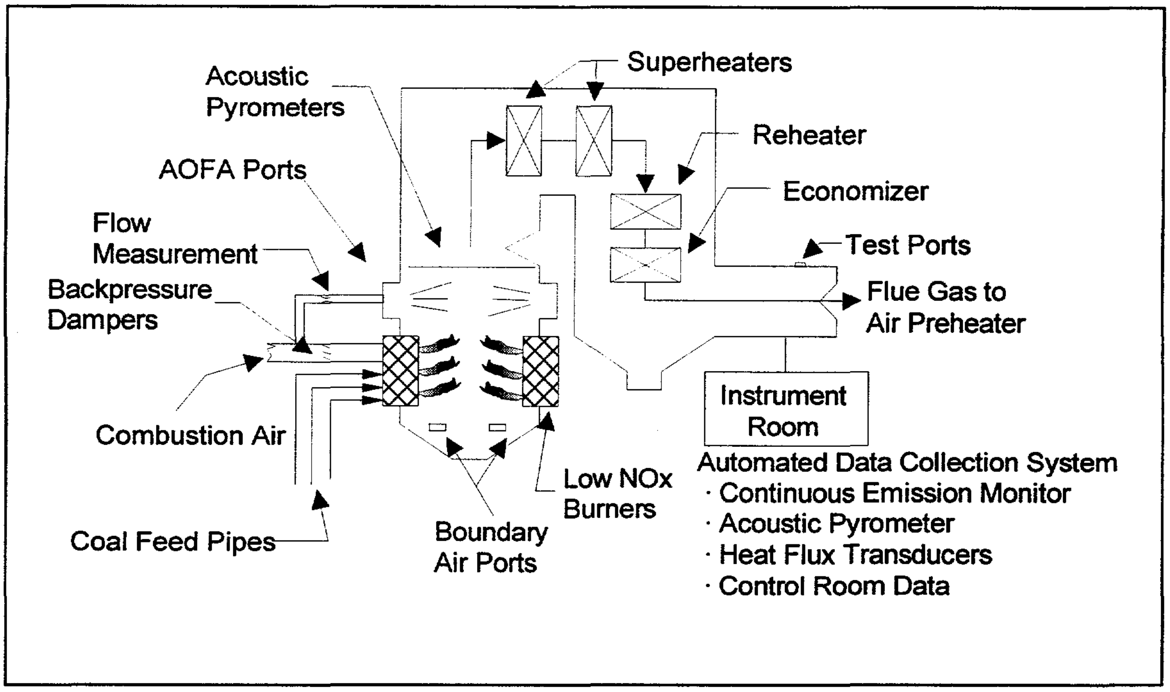


Figure 1: Plant Hammond Unit 4 Boiler

The data acquisition system (DAS) for the Hammond Unit 4 ICCT project is a custom-designed microcomputer-based system used to collect, format, calculate, store, and transmit data derived from power plant mechanical, thermal, and fluid processes. The extensive process data selected for input to the DAS has in common a relationship with either boiler performance or boiler exhaust gas properties. This system includes a continuous emissions monitoring system (NO_x, SO_2, O_2, THC, CO) with a multi-point flue gas sampling and conditioning system, an acoustic pyrometry and thermal mapping system, furnace tube heat flux transducers, and boiler efficiency instrumentation. The instrumentation system is designed to provide data collection flexibility to meet the schedule and needs of the various testing efforts throughout the demonstration program. A summary of the type of data collected is shown in Table 2.

During each test phase, a series of four groups of tests are conducted. These are: (1) diagnostic, (2) performance, (3) long-term, and (4) verification. The diagnostic, performance, and verification tests consist of short-term data collection during carefully established operating conditions. The diagnostic tests are designed to map the effects of changes in boiler operation on NO_x emissions. The performance tests evaluate a more comprehensive set of boiler and combustion performance indicators. The results from these tests will include particulate characteristics, boiler efficiency, and boiler outlet emissions. Mill performance and air flow distribution are also tested. The verification tests are performed following the end of the long-term testing period and serve to identify any potential changes in plant operating conditions.

Table 2: Inputs to Data Acquisition System

Boiler Drum Pressure	Superheat Outlet Pressure
Cold Reheat Pressure	Hot Reheat Pressure
Barometric Pressure	Superheat Spray Flow
Reheat Spray Flow	Main Steam Flow
Feedwater Flow	Coal Flows
Secondary Air Flows	Primary Air Flows
Main Steam Temperature	Cold Reheat Temperature
Hot Reheat Temperature	Feedwater Temperature
Desuperheater Outlet Temp.	Desuperheater Inlet Temp.
Economizer Outlet Temp.	Air Heater Air Inlet Temp.
Air Heater Air Outlet Temp.	Ambient Temperature
BFP Discharge Temperature	Relative Humidity
Stack NOx	Stack SO2
Stack O2	Stack Opacity
Generation	Overfire Air Flows

As stated previously, the primary objective of the demonstration is to collect long-term, statistically significant quantities of data under normal operating conditions with and without the various NO_x reduction technologies. Earlier demonstrations of emissions control technologies have relied solely on data from a matrix of carefully established short-term (one- to four-hour) tests. However, boilers are not typically operated in this manner, considering plant equipment inconsistencies and economic dispatch strategies. Therefore, statistical analysis methods for long-term data are available that can be used to determine the achievable emissions limit or projected emission tonnage of an emissions control technology. These analysis methods have been developed over the past fifteen years by the Control Technology Committee of the Utility Air Regulatory Group (UARG). Because the uncertainty in the analysis methods is reduced with increasing data set size, UARG recommends that acceptable 30 day rolling averages can be achieved with data sets of at least 51 days with each day containing at least 18 valid hourly averages.

2.2. Unit Description

Georgia Power Company's Plant Hammond Unit 4 is a Foster Wheeler Energy Corporation (FWEC) opposed wall-fired boiler, rated at 500 MW gross, with design steam conditions of 2500 psig and 1000/1000°F superheat/reheat temperatures, respectively. The unit was placed into commercial operation on December 14, 1970. Prior to the LNB retrofit, six FWEC Planetary Roller and Table type mills provided pulverized eastern bituminous coal (12,900 Btu/lb, 33% VM, 53% FC, 1.7% S, 1.4% N) to 24 pre-NSPS, Intervane burners. During the LNB outage, the existing burners were replaced with FWEC Control Flow/Split Flame burners. The unit was also retrofit with six Babcock and Wilcox MPS 75 mills during the course of the demonstration (two each during the spring 1991, spring 1992, and fall 1993 outages). The burners are arranged in a matrix of 12 burners (4W x 3H) on opposing walls with each mill supplying coal to 4 burners per elevation. As part of this demonstration project, the unit was retrofit with an advanced overfire air system, to be described later. The unit is equipped with a cold-side

ESP and utilizes two regenerative secondary air pre-heaters and two regenerative primary air heaters. The unit was designed for pressurized furnace operation but was converted to balanced draft operation in 1977. The unit, equipped with a Bailey pneumatic boiler control system during the baseline, AOFA, LNB, and LNB+AOFA phases of the project, was retrofit with a Foxboro I/A distributed digital control system for Phase 4 of the project.

2.3. Advanced Overfire Air (AOFA) System

Generally, combustion NO_x reduction techniques attempt to stage the introduction of oxygen into the furnace. This staging reduces NO_x production by creating a delay in fuel and air mixing that lowers combustion temperatures. The staging also reduces the quantity of oxygen available to the fuel-bound nitrogen. Typical overfire air (OFA) systems accomplish this staging by diverting 10 to 20 percent of the total combustion air to ports located above the primary combustion zone. AOFA improves this concept by introducing the OFA through separate ductwork with more control and accurate measurement of the AOFA airflow, thereby providing the capability of improved mixing (Figure 2).

Foster Wheeler Energy Corporation (FWEC) was competitively selected to design, fabricate, and install the advanced overfire air system and the opposed-wall, low NO_x burners described below. The FWEC design diverts air from the secondary air ductwork and incorporates four flow control dampers at the corners of the overfire air windbox and four overfire air ports on both the front and rear furnace walls. As a result of budgetary and physical constraints, FWEC designed an AOFA system more suitable to the project and unit than that originally proposed. Six air ports per wall were proposed, whereas four ports per wall were installed.

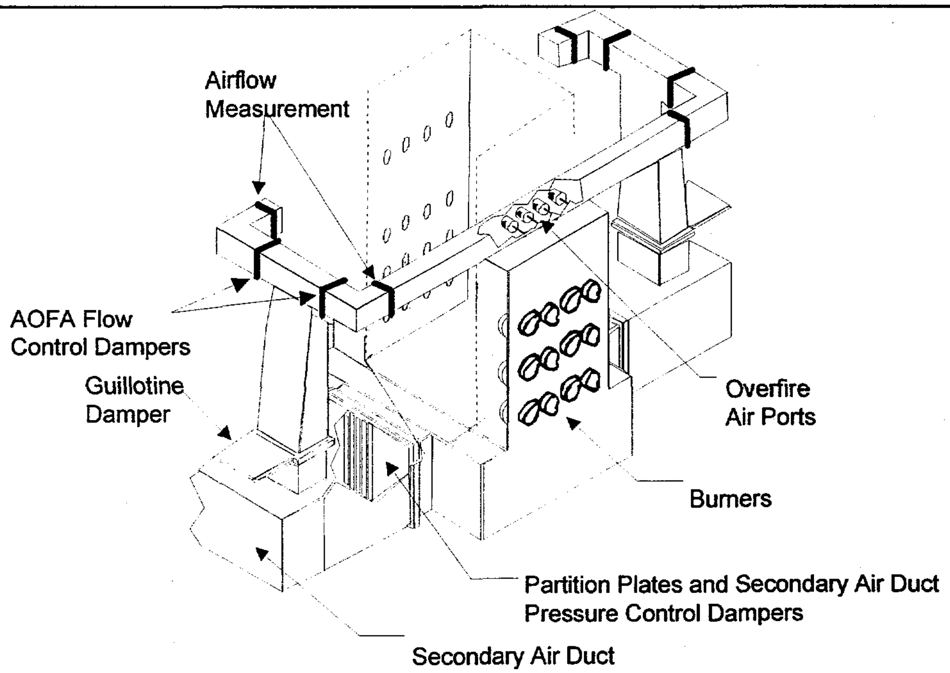


Figure 2: Advanced Overfire Air System

2.4. Low NO_x Burners

Low NO_x burner systems attempt to stage the combustion without the need for the additional ductwork and furnace ports required by OFA and AOFA systems. These commercially-available burner systems introduce the air and coal into the furnace in a well controlled, reduced turbulence manner. To achieve this, the burner must regulate the initial fuel/air mixture, velocities and turbulence to create a fuel-rich core, with sufficient air to sustain combustion at a severely sub-stoichiometric air/fuel ratio. The burner must then control the rate at which additional air, necessary to complete combustion, is mixed with the flame solids and gases to maintain a deficiency of oxygen until the remaining combustibles fall below the peak NO_x producing temperature (around 2800°F). The final excess air can then be allowed to mix with the unburned products so that the combustion is completed at lower temperatures. Burners have been developed for single-wall and opposed wall boilers.

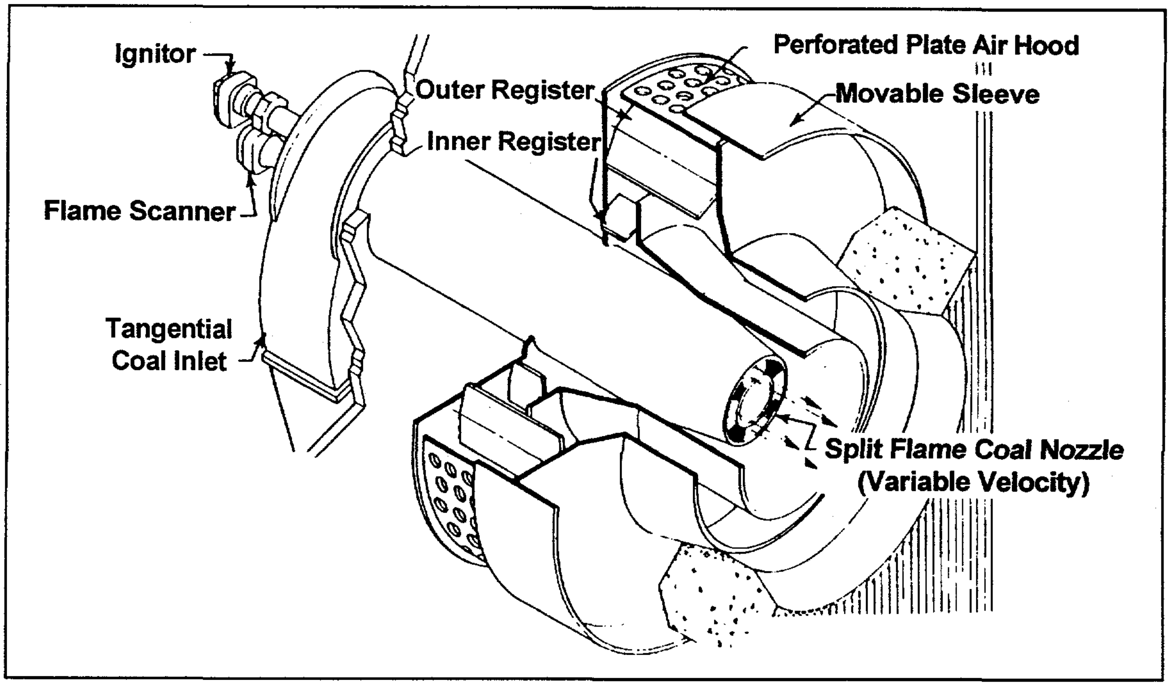


Figure 3: Low NO_x Burner Installed at Plant Hammond

In the FWEC Controlled Flow/Split Flame (CFSF) burner (Figure 3), secondary combustion air is divided between inner and outer flow cylinders. A sliding sleeve damper regulates the total secondary air flow entering the burner and is used to balance the burner air flow distribution. An adjustable outer register assembly divides the burners secondary air into two concentric paths and also imparts some swirl to the air streams. The secondary air which traverses the inner path, flows across an adjustable inner register assembly that, by providing a variable pressure drop, apportions the flow between the inner and outer flow paths. The inner register also controls the degree of additional swirl imparted to the coal/air mixture in the near throat region. The outer air flow enters the furnace axially, providing the remaining air necessary to complete combustion. An axially movable inner sleeve tip provides a means for varying the primary air velocity while maintaining a constant primary flow. The split flame nozzle segregates the coal/air mixture into four concentrated streams, each of which forms an individual flame when entering the furnace. This segregation minimizes mixing between the coal and the primary air, assisting in the staged combustion process. The adjustments to the sleeve dampers, inner registers, outer registers, and tip position are made during the burner optimization process and thereafter remain fixed unless changes in plant operation or equipment condition dictate further adjustments.

2.5. Application of Advanced Digital Control Methodologies

The objective of Phase 4 of the project is to implement and evaluate an advanced digital control/optimization system for use with the combustion NO_x abatement technologies installed on Plant Hammond Unit 4. The advanced system will be customized to minimize NO_x production while simultaneously maintaining and/or improving boiler performance and safety margins. This project will provide documented effectiveness of an advanced digital control /optimization strategy on NO_x emissions and guidelines for retrofitting boiler combustion controls for NO_x emission reduction. The methodology selected for demonstration at Hammond Unit 4 during Phase 4 of the project is the Generic NO_x Control Intelligent System (GNOCIS). The major elements of GNOCIS are shown in Figure 4.

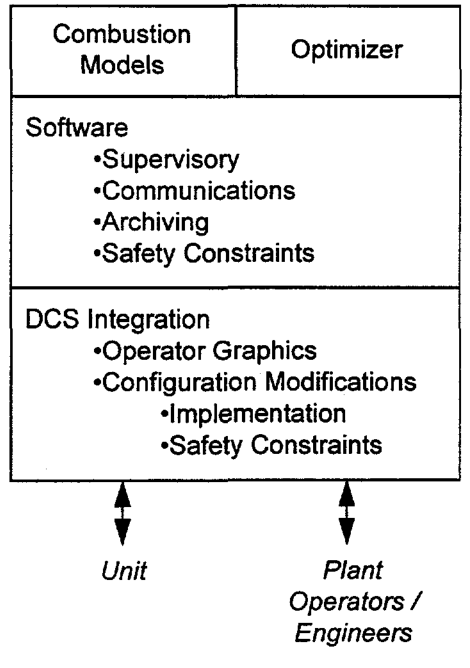


Figure 4: Major Elements of GNOCIS

3. PROJECT STATUS

3.1. Project Summary

Baseline, AOFA, LNB, and LNB+AOFA test phases have been completed. Details of the testing conducted during each phase can be found in the following reports:

- Phase 1 Baseline Tests Report [1],
- Phase 2 AOFA Tests Report [2],
- Phase 3A Low NO_x Burner Tests Report [3], and
- Phase 3B Low NO_x Burner plus AOFA Tests Report [4].

Chemical emissions testing was also conducted as part of the project and the results have been previously reported [5]. Phase 4 of the project -- evaluation of advanced digital optimization / controls strategies as applied to NO_x abatement -- is now in progress. A list of the current activities and their current status can be found in Table 3.

Table 3: Phase 4 Milestones / Status

Milestone	Status
Digital control system design, configuration, and installation	Completed
Digital control system startup	Completed
Instrumentation upgrades	Completed
Characterization of the unit pre- activation of advanced strategies	Completed
Advanced controls/optimization design	In Progress
Characterization of the post- activation of advanced strategies	10/95 - 12/95*

*Pending unit availability

3.2. Summary of Current Quarter Activities

During third quarter 1995, prototypes of the Generic NO_x Control Intelligent System (GNOCIS) continue to be tested at Alabama Power Company's Gaston Unit 4 and PowerGen's Kingsnorth Unit 1. Progress continued to be made on the installation of GNOCIS at Hammond 4 and modifications necessary for open- or closed-loop operation are virtually complete. Delays in delivery of the GNOCIS software package and unit unavailability have adversely impacted the demonstration schedule. Process data continues to be collected for use in model development. Although it is believed a suitable model has been created, refinements are continuing to be made in an effort to improve the robustness of the model prior to testing on the unit. The unit is currently off-line due to low generation demand. Upon resumption of consistent unit operation, approximately two months of GNOCIS testing will be conducted. Short-term, diagnostic tests were conducted during August 1995. The primary purpose of these tests were to determine the performance characteristics of the three on-line carbon-in-ash monitors installed on this unit. Further testing of these monitors is planned following resumption of unit operation. The draft Public Design Report was issued during September and is undergoing review by all project participants. The project is now scheduled for completion by December 31, 1995, however to accommodate delays associated with Phase 4, a project extension has been requested.

3.3. Short-Term Tests

On August 20 and 21, 1995, nine diagnostic tests were conducted (Table 4). During each test, composite samples were collected isokinetically from the "A" and "B" ducts just prior to the precipitator. These samples were collected at three different loads (300, 400, and 520 MW) and excess O_2 levels (low, nominal, and high). In addition to the composite duct samples, samples were collected from the front row of precipitator hoppers during each tests. As in previous short-term tests, data was also collected on the project's data acquisition system and digital control system.

The goals of these tests were twofold:

- Provide further information concerning the performance characteristics of the unit, and
- Provide reference data to be used in the evaluation of the three on-line carbon-in-ash analyzers installed on the unit.

Aspects concerning the first goal are discussed below. Results pertaining to the carbon-in-ash analyzers are discussed in Section 3.6.

NO_x emissions, CO emissions, and carbon-in-ash as a function of stack O_2 are shown in Figures 5, 6, and 7, respectively. For the 400 and 500 MW load levels tested, the NO_x / O_2 gradient was near 0.08 lb/MBtu/percent while at 300 MW, the sensitivity was lower at 0.05 lb/MBtu/percent. For comparison, during Phase 3B testing conducted during 1993, the sensitivity varied from 0.08 to 0.03 lb/MBtu/percent. As experienced during prior testing, CO emissions were relatively low at nominal excess O_2 levels (Table 4 and Figure 6). Carbon-in-ash vs. stack O_2 is shown in Figure 7. As shown, the slope (approximately -2.2 percent carbon per percent change in oxygen) of the characteristic was approximately the same at the three load levels tested.

Table 4: Summary of Diagnostics Tests Conducted Third Quarter 1995

Test	Date	Start	End	Description	Unit Load (MW)	Stack O2 Percent	Stack NOx lb/MBtu	Stack CO ppm	Carbon-in-Ash Percent
150-1	20-Jul-95	11:20	12:55	Full-Load / Low O2	519	5.0	0.39	119	8.0
150-2	20-Jul-95	14:15	15:55	Full-Load / Med. O2	520	6.0	0.45	12	5.6
150-3	20-Jul-95	16:40	18:15	Full-Load / Hi O2	500	6.7	0.54	4	4.5
151-1	21-Jul-95	0:20	1:45	Low-Load / Low O2	305	5.6	0.36	50	7.5
151-2	21-Jul-95	2:25	3:50	Low-Load / Med. O2	305	6.8	0.43	5	3.6
151-3	21-Jul-95	4:30	6:00	Low-Load / Hi O2	305	8.1	0.49	5	2.0
151-4	21-Jul-95	7:10	8:10	Med-Load / Low O2	400	5.6	0.35	46	7.4
151-5	21-Jul-95	8:40	9:40	Med-Load / Med. O2	400	6.3	0.43	10	5.6
151-6	21-Jul-95	10:20	11:15	Med-Load / Hi O2	400	7.5	0.51	8	3.5

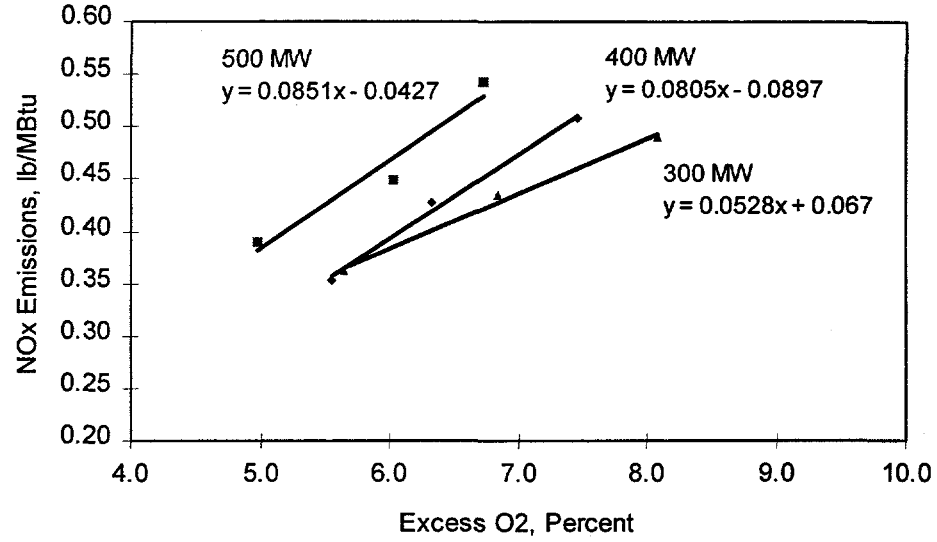


Figure 5: July 1996 Short-Term Tests - NO_x Emissions vs. Stack O_2

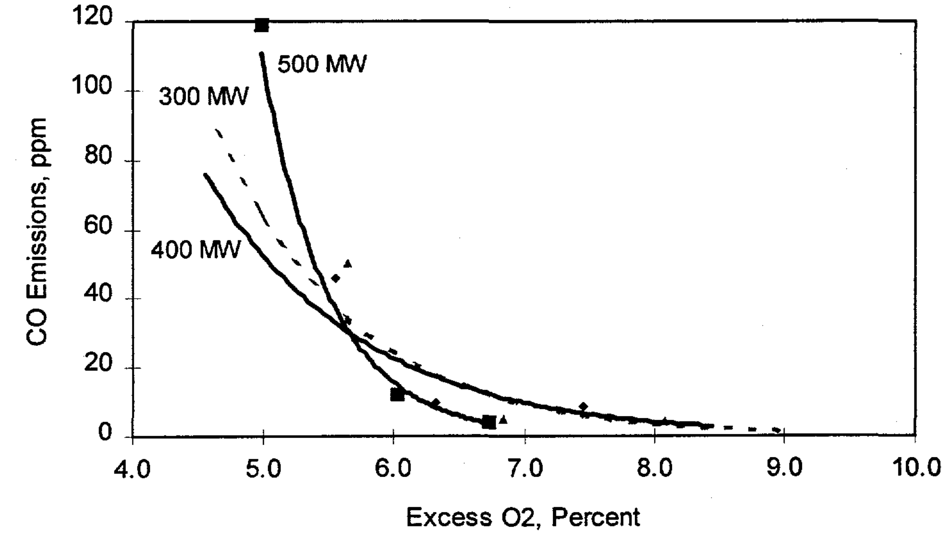


Figure 6: July 1996 Short-Term Tests - CO Emissions vs. Stack O_2

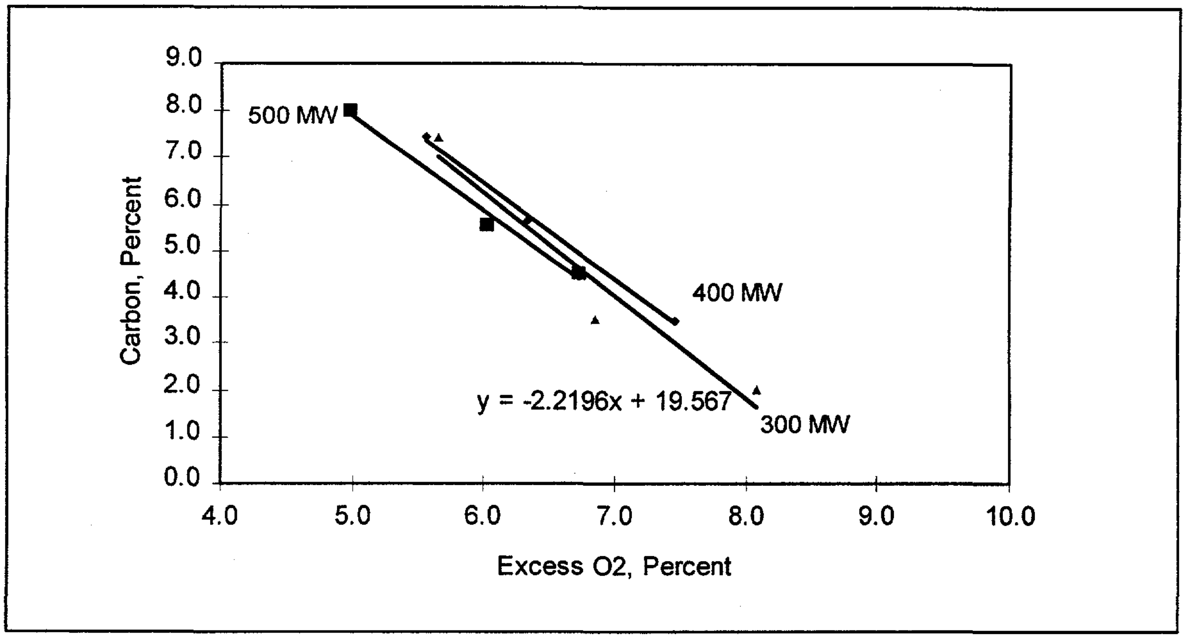


Figure 7: July 1996 Short-Term Tests - Fly Ash Carbon vs. Stack O_2

3.4. Long-Term Generation and Emissions

Long-term data collection continued during this quarter. Unit generation is shown in Figures 8 and 9. As shown, the unit was run at minimum (approximately 200 MW) to maximum loads (approximately 540 MW) during this quarter. The unit operated at a capacity factor of near 56 percent and was off-line approximately 6 percent this period. Average load was approximately 305 and 325 MW when off-time was included and excluded, respectively. NO_x emissions for this period are shown in Figures 10 through 12. The average NO_x emission rate for the period was 0.43 lb/MBtu -- the emission rate during Phase 3B was approximately 0.40 lb/MBtu. The reason for the increase in emissions is at this time unknown. The current quarter emission rate is only slightly different than the prior quarter (0.44 lb/Mbtu). The emission limit for this unit is 0.50 lb/MBtu. As in prior phases, NO_x emissions were rather independent of unit load (Figure 12). The band around the mean represents ± two standard deviations. SO_2 emissions during this quarter are shown in Figures 13 through 15. SO_2 emissions were generally consistent during this quarter. The mean SO_2 emission rate for the quarter was approximately 4700 lb/hr with total emissions for the period being near 5200 tons. As shown in Figure 15, the SO_2 emission rate, as expected, is linearly related to load. Stack gas mass flow rates for the period are depicted in Figures 16 through 18. As shown, mean gas flow rate is roughly linear with load.

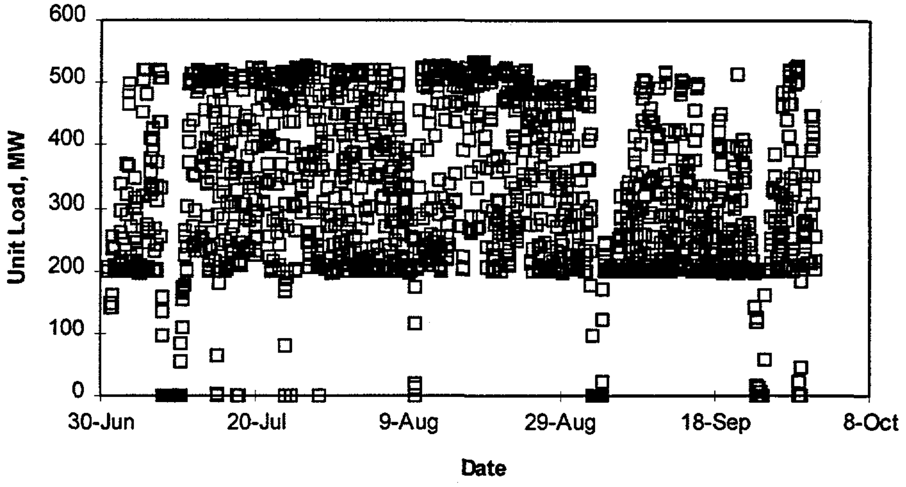


Figure 8: Third Quarter 1995 Generation

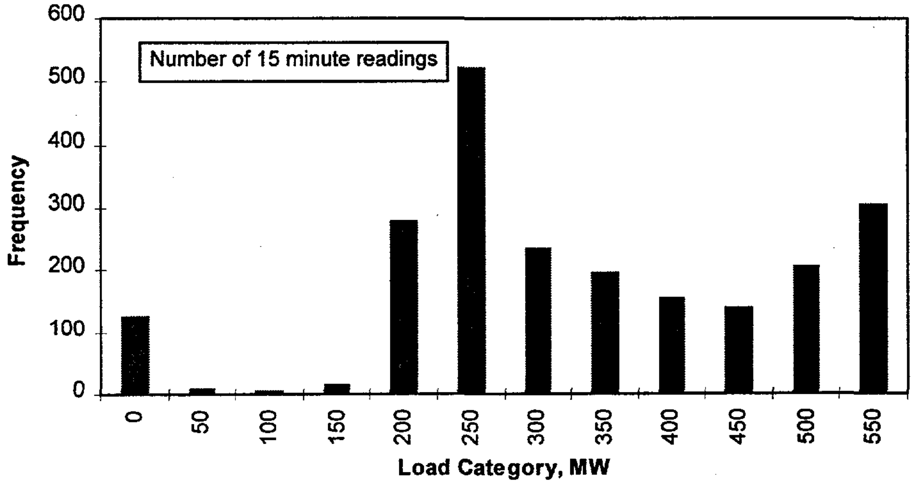


Figure 9: Third Quarter 1995 Generation Histogram

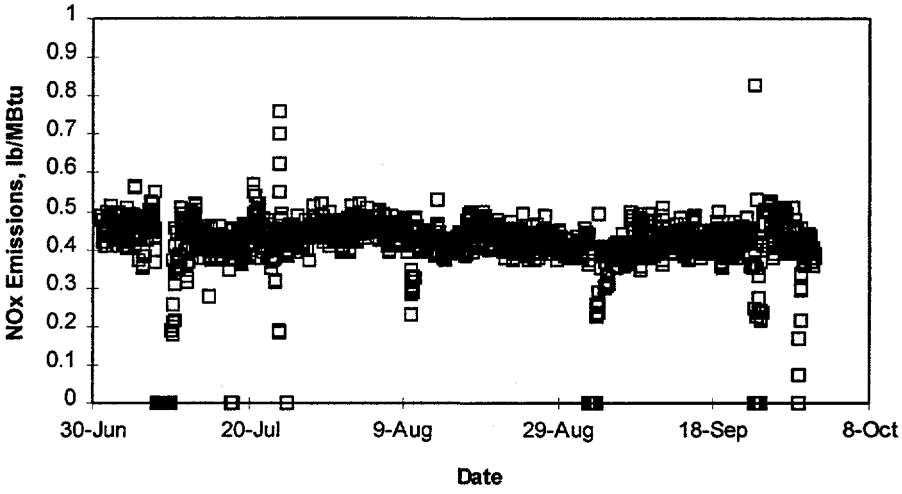


Figure 10: Third Quarter 1995 NO_x Emission Levels

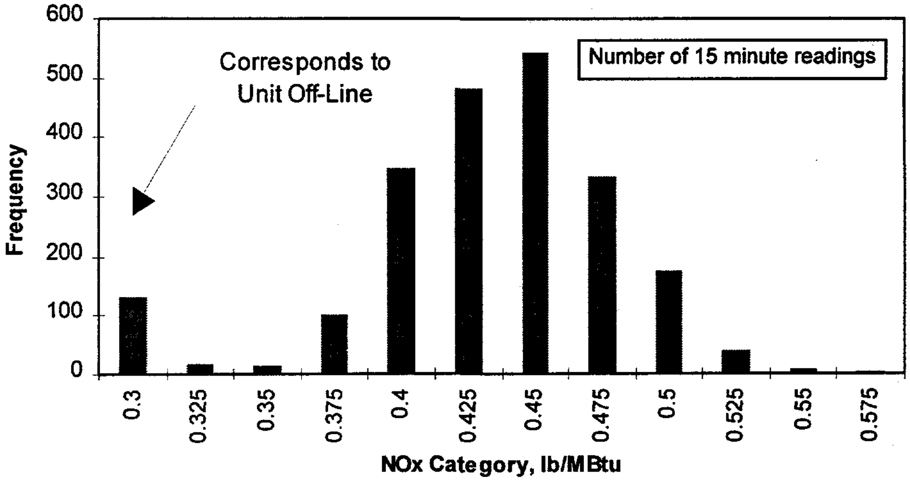


Figure 11: Third Quarter 1995 NO_x Emission Level Histogram

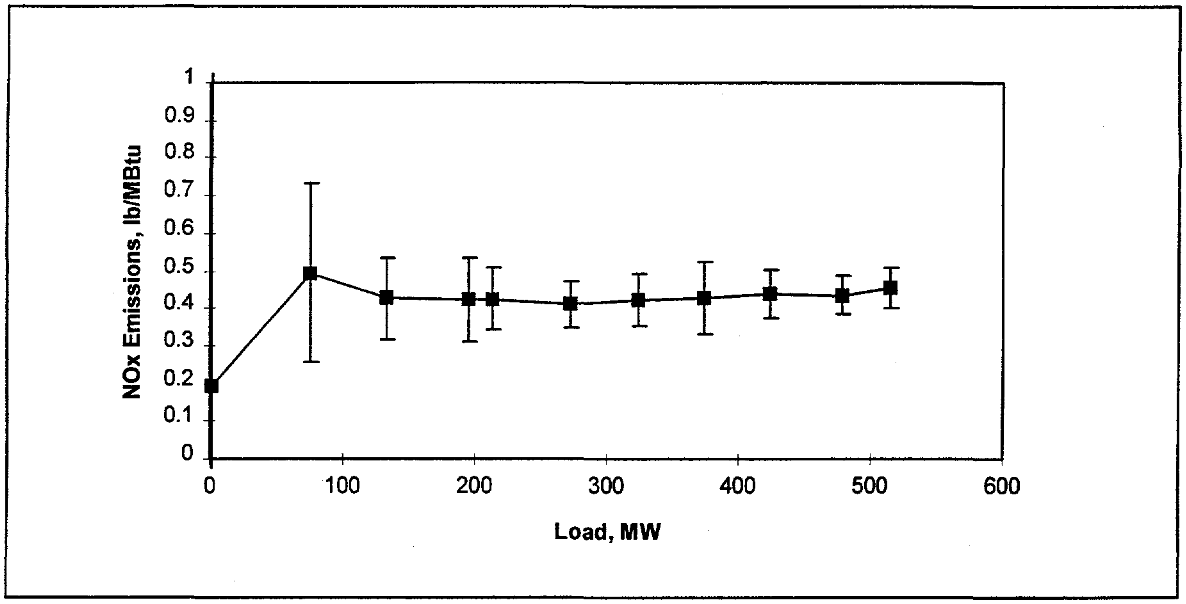


Figure 12: Third Quarter 1995 NO_x Emission vs. Load Characteristic

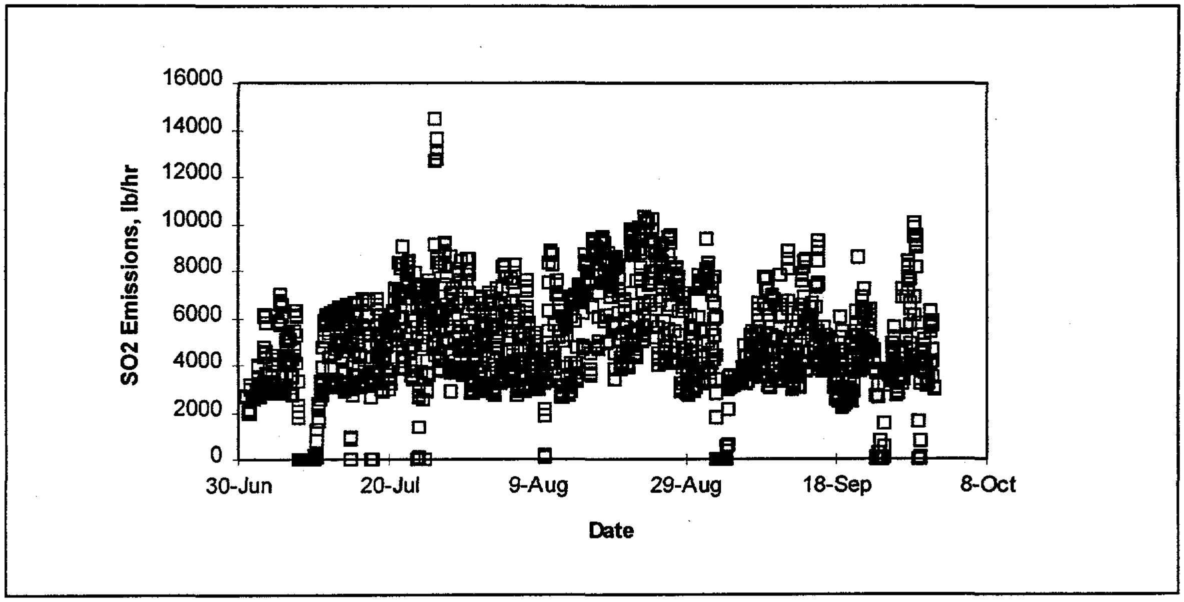


Figure 13: Third Quarter 1995 SO_2 Emission Levels

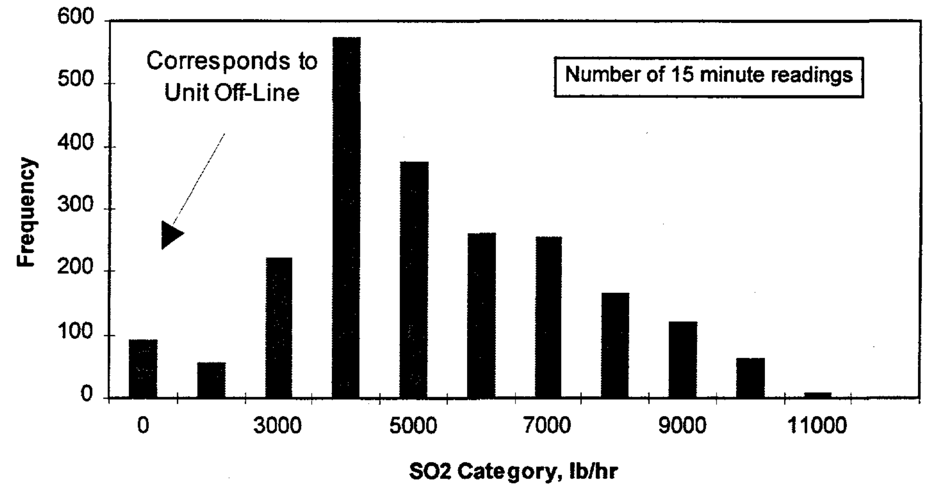


Figure 14: Third Quarter 1995 SO_2 Emission Histogram

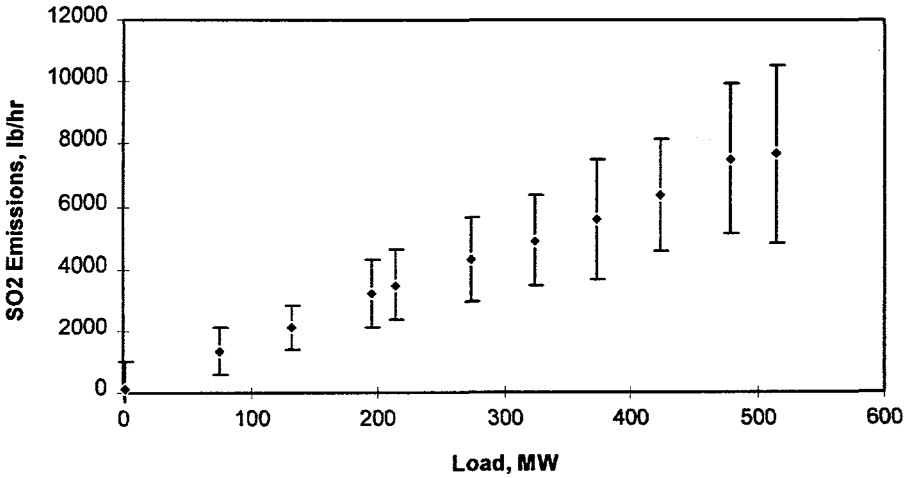


Figure 15: Third Quarter 1995 SO_2 Emissions vs. Load Characteristic

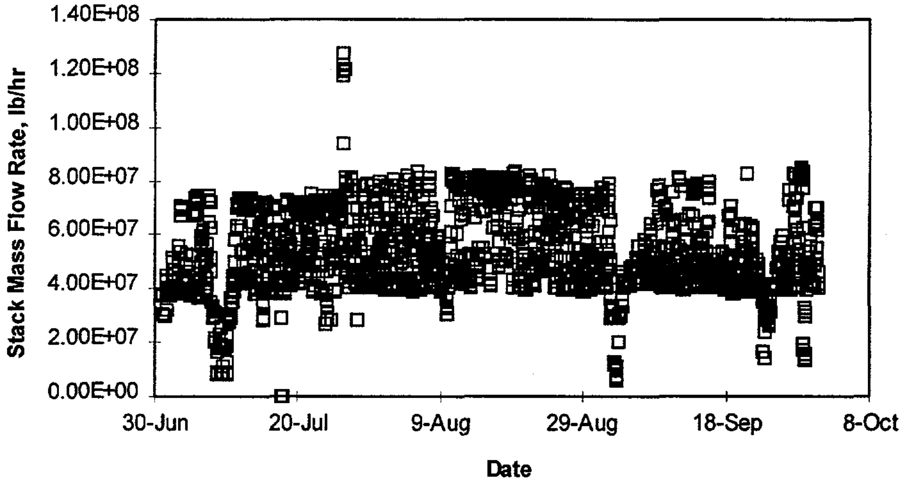


Figure 16: Third Quarter 1995 Stack Mass Flow Rate Levels

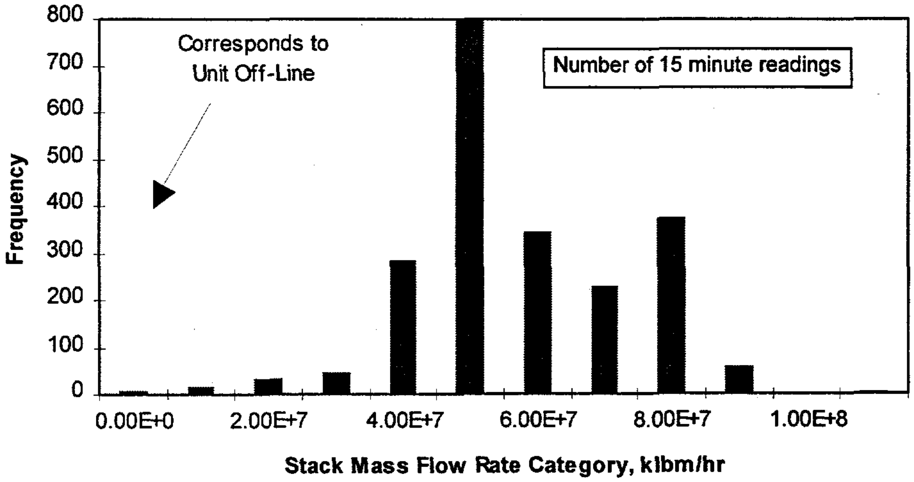


Figure 17: Third Quarter 1995 Stack Mass Flow Rate Histogram

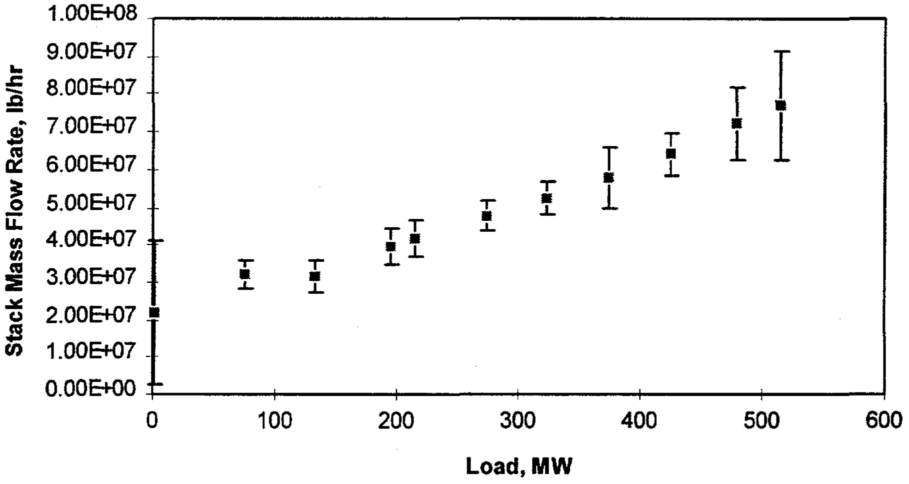


Figure 18: Third Quarter 1995 Stack Mass Flow Rate vs. Load Characteristic

3.5. Advanced Controls and Optimization

The software and methodology to be demonstrated at Hammond Unit 4 is the Generic NO_x Control Intelligent System (GNOCIS) whose development is being funded by a consortium consisting of the Electric Power Research Institute, PowerGen (a U.K. power producer), Southern Company, U.K. Department of Trade and Industry, and U.S. Department of Energy [6]. GNOCIS is a methodology that can result in improved boiler efficiency and reduced NO_x emissions from fossil fuel fired boilers. Using a numerical model of the combustion process, GNOCIS applies an optimizing procedure to identify the best set points for the plant on a continuous basis. The optimization occurs over a wide range of operating conditions. Once determined, the recommended setpoints can be implemented automatically without operator intervention (closed-loop), or, at the plant's discretion, conveyed to the plant operators for implementation (open-loop). GNOCIS is designed to run on a stand-alone workstation networked to the digital control system, or internally on some digital control systems.

GNOCIS is currently under development and has been or is scheduled to be implemented at PowerGen's Kingsnorth Unit 1 (a 500 MW tangentially-fired unit with ICL separated and close-coupled overfire air low NO_x combustion system) and Alabama Power's Gaston Unit 4 (a 250 MW B&W unit with B&W XCL low NO_x burners) prior to comprehensive testing at Hammond. Following "re-characterization" of Hammond 4, the advanced controls and optimization strategies will be activated and run open-loop. If the results from the open-loop testing warrant, the advanced controls/optimization package will be operated closed-loop with testing (short- and long-term). A brief review of the major developments during the current quarter regarding the GNOCIS activities at Gaston, Kingsnorth, and Hammond are provided below.

Gaston

A summary of the activities and status of the GNOCIS project at Gaston Unit 4 follows:

- Version 3.1 of Pavilion's Process Insights is now being used for GNOCIS development and as part of the GNOCIS run-time routines. This new release corrected problems associated with the optimizer and allows the use of non-model variables in the optimizer. Although some deficiencies still exist, based on testing to date, the current version appears to be sufficiently robust to serve as a component of GNOCIS.

- The GNOCIS software for Gaston is now approximately 95 percent complete with only enhancements and future bug fixes planned. Two enhancements planned are:

    ◊ Installation of an improved archiver - The historian provided by Leeds & Northrup as part of the DCS has been problematic and difficult to use. To accommodate the needs of the project on an interim basis, an archiver resident on the GNOCIS host platform was installed. An improved archiver was later installed on the DCS at Hammond Unit 4 which will be migrated to the Gaston GNOCIS installation.

  - ◊ Development of software to allow modification of constraints from DCS - Presently, the primary GNOCIS interface resides on a Windows NT platform running Wonderware's InTouch. Although superior in many respects to the L&N DCS operator interface, for long-term operation at this site, the GNOCIS interface must be incorporated into the DCS. Operator graphics and the underlying software are now in place to display GNOCIS recommendations on the DCS, however, currently constraints and limits cannot be modified from the DCS. Although during normal operation these functions will be used infrequently, they will be incorporated into the DCS to facilitate their use by plant staff.

- On-site testing of GNOCIS continued at Gaston during September 1995. In total, seventeen diagnostic tests were conducted during the month, all at full-load (270 MW). In general, predictions and recommendations made by the GNOCIS software were relatively robust, particularly during the latter tests. Summaries of these tests are attached. The data collected from these tests, along with normal operating data will be used for model retraining. Approximately thirty additional tests are planned at full, intermediate, and low loads. Pending unit availability, these tests will be completed during October 1995. Additional testing will be conducted as project budget permits.

- Current plans are to remove the temporary continuous emissions monitor (CEM) installed on Gaston Unit 4 following the completion of GNOCIS testing. Therefore if GNOCIS is to be maintained at the site, accommodations must be made to obtain NO_x and CO emissions data. Options include: (1) installation of a permanent CEM for Unit 4, (2) periodic use of a CEM test trailer, and (3) use of the combined Unit 3-4 compliance CEM.

Kingsnorth

Testing of GNOCIS at Kingsnorth has been completed and GNOCIS is now being used in a production mode at the plant. Further ad hoc testing of GNOCIS may be conducted at Kingsnorth later this year. The current GNOCIS installation at Kingsnorth is based on a linear model and constrained linear optimization routines. In the future, this installation may be modified to incorporate the non-linear models such as those used at Gaston and Hammond.

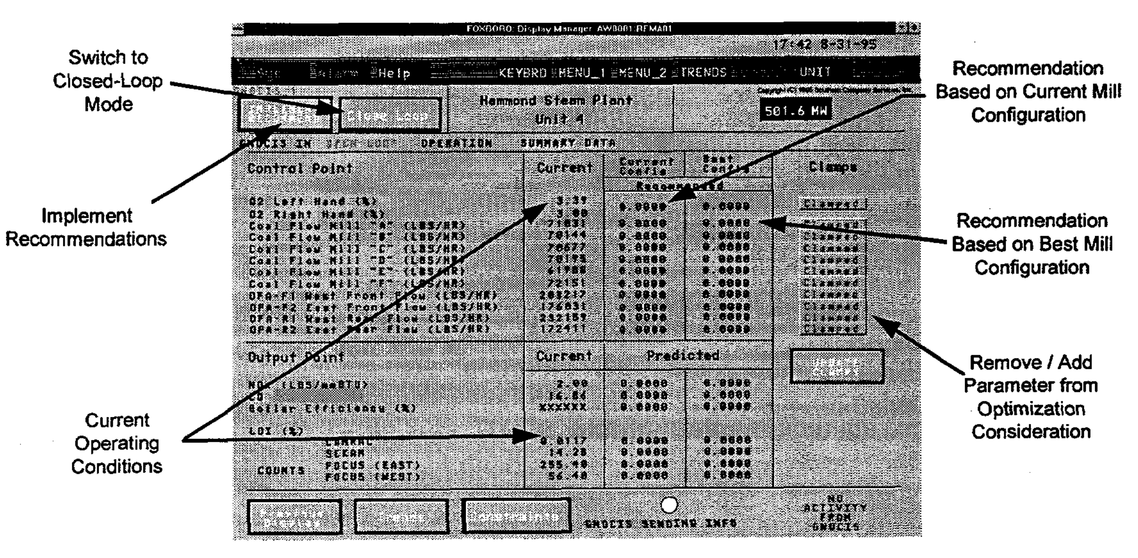
Hammond

A summary of the activities and status of, as related to the demonstration of GNOCIS at Hammond, follows:

- Delays in software delivery continue to adversely impact the project schedule. The project is now scheduled for completion by December 31, 1995, however to accommodate final reporting and close-out, a project extension to June 1996 has been requested.

- Final software coding is now in progress. As a result of heavy loading of the Foxboro I/A Control Processors and Fieldbus, re-writing of some portions of supporting GNOCIS software was necessary to minimize network conflicts and data loss.
- The DCS control logic and operator graphics have been developed to allow both open- and closed-loop operation of GNOCIS. The primary operator graphic is shown in Figure 19. As shown, the operator is able to perform the following functions from this screen:
  - ◊ Implement open-loop recommendations - The operator can implement these recommendations with selection of the implement button.
  - ◊ Enable and disable closed-loop operation of GNOCIS - When in closed-loop mode, the recommendations are implemented automatically and continuously without further operator intervention.
  - ◊ Disable or enable control parameters - The operator can remove and add back selected control parameters from optimization consideration. For example, if mill "A" had to be run at some fixed load, the operator would remove this mill from the optimization mix and GNOCIS would generate recommendations that reflects that this mill is not available for optimization purposes.

Also provided on this graphic are the current operating conditions and predictions of the operating conditions at the recommended set points. Other graphics are provided that enable plant staff to change goals and limits on-line.



Control Point	Current	Current Config Recommended	Best Config Recommended	Clamps
O2 Left Hand (%)	3.39	0.0000	0.0000	Clamped
O2 Right Hand (%)	3.00	0.0000	0.0000	Clamped
Coal Flow Mill "A" (LBS/HR)	71831	0.0000	0.0000	Clamped
Coal Flow Mill "B" (LBS/HR)	70144	0.0000	0.0000	Clamped
Coal Flow Mill "C" (LBS/HR)	70677	0.0000	0.0000	Clamped
Coal Flow Mill "D" (LBS/HR)	70175	0.0000	0.0000	Clamped
Coal Flow Mill "E" (LBS/HR)	61788	0.0000	0.0000	Clamped
Coal Flow Mill "F" (LBS/HR)	72151	0.0000	0.0000	Clamped
OFA-F1 West Front Flow (LBS/HR)	203217	0.0000	0.0000	Clamped
OFA-F2 East Front Flow (LBS/HR)	176831	0.0000	0.0000	Clamped
OFA-R1 West Rear Flow (LBS/HR)	232159	0.0000	0.0000	Clamped
OFA-R2 East Rear Flow (LBS/HR)	172411	0.0000	0.0000	Clamped

Output Point	Current	Predicted	
NOx (LBS/mmBTU)	2.00	0.0000	0.0000
CO	16.86	0.0000	0.0000
Boiler Efficiency (%)	XXXXXX	0.0000	0.0000
LOI (%) CAMRAC	0.0117	0.0000	0.0000
SECAM	14.28	0.0000	0.0000
COUNTS FOCUS (EAST)	255.40	0.0000	0.0000
FOCUS (WEST)	56.40	0.0000	0.0000

Figure 19: GNOCIS Operator Interface

- Using long-term data collected through September 1995, Radian continues to develop prediction and control models. Based on (1) an analysis of the data collected to date and (2) potential control parameters, the following controllable parameters are to be used initially at Hammond 4: (1) individual fuel flow demands, (2) overfire air flows or overfire air flow dampers, and (3) overall excess oxygen. Data from March through August 1995 have been retrieved from the DCS and are being used for training of the combustion models. Radian is now developing models to be used in testing at Hammond.

3.6. On-Line Carbon-in-Ash Monitors

A subsidiary goal of the Wall-Fired project is the evaluation of advanced instrumentation as applied to combustion control. Based on this goal, three on-line carbon-in-ash (CIA) monitors have been procured for this project and are being evaluated as to their:

- Reliability and maintenance,
- Accuracy and repeatability, and
- Suitability for use in the control strategies being demonstrated at Hammond Unit 4.

A Clyde-Sturtevant SEKAM monitor samples from two fixed locations at the economizer outlet. The outputs (carbon-in-ash and system alarm) have been connected to the DCS for archival purposes and incorporation into the control logic. This monitor was commissioned during November 1994. A CAMRAC Corporation CAM monitor, installed February 1995, samples from a single movable location at the precipitator inlet. An Applied Synergistics' FOCUS, commissioned July 1995, is installed near the nose of the furnace. These CAM and SEKAM were described previously in the *Third Quarter 1994 Technical Progress Report.* The FOCUS system was described in the *Second Quarter 1995 Technical Progress Report.*

The first round of testing of these instruments were conducted July 20 and 21, 1995. During each of the nine tests, composite duct samples were collected from the flue gas stream at the precipitator inlet - one each from the A and B side of the precipitator. These samples were collected at three different loads (500, 400, and 300 MW) and oxygen levels (low, nominal, and high). In addition to the composite duct samples, precipitator hopper samples were collected from the first row of hoppers (out of three rows total) on the A and B sides during each test. An effort was made to clear the hoppers before each test. The first row of hoppers typically receive near 80 percent of the fly ash collected by the precipitator.

Aspects of the accuracy of these instruments include:

- Representativeness of Sample Used in the Analysis (Spatial) - For all these instruments, only a subset of the ash passing into the precipitator is observed or collected for further analysis. Since this flue gas/ash stream is in general non-homogenous, the sampling technique can lead to substantial error in the estimate.
- Accuracy of the Measurement Techniques (Inherent) - All the devices tested infer carbon content of the "collected" sample indirectly. SEKAM uses a correlation based on sample capacitance, CAM uses microwave absorption, and FOCUS uses a

method based on hot particle counting. The accuracy of these techniques depend on numerous assumptions concerning the characteristics of the flue gas/ash stream.

- Timeliness (Temporal) - Delays and time lags in the sampling and analysis mechanisms employed by the instruments affect their use for on-line control of fly ash carbon.

Results of the testing conducted with the carbon-in-ash analyzers this quarter are discussed below.

Percent Carbon vs. LOI

Loss-on-ignition (LOI) is a measure of the combustibles contained in a sample and is used frequently to represent carbon content of the sample; however, the two are not synonymous. The LOI indication is also affected by other non-carbonaceous combustible material in the ash, such as sulfur.

As can be seen from Figure 20, for the ash collected at Hammond, LOI is an excellent estimator of the carbon content in the sample. As a result of other combustibles in the ash sample, the LOI percentage is slightly greater (less than 0.5 percent) than the carbon percentage.

Using Hopper Samples to Estimate Boiler Carbon Losses

In most instances, it is easier and less time consuming to obtain fly ash to be used in determining boiler carbon losses from the precipitator hoppers rather than from the flue gas stream directly. However, there are numerous problems with this approach including:

- Correlating ash collection times with boiler operating conditions, and
- Weighting of the collected ash samples so that the combined sample is representative of the ash in the flue gas stream.

These problems are not substantially different than that of the carbon-in-ash monitors. Because this method is used frequently, it was felt that it would serve as a useful benchmark for the other methods. Figures 21 through 26 show results from Tests 150 and 151 conducted on July 21 and 22. As shown from their low sensitivity to change in ash conditions (Figure 21), samples collected from hoppers A3 and A4 did not provide information useful for LOI predictions whereas the other hopper samples did show a positive trend with increasing LOI levels (Figures 21 and 23). The composite sensitivity where the individual hopper samples are weighted equally is shown in Figure 25. A slightly better fit is obtained when the least squares linear correlation is applied to the individual hopper LOIs (Figure 26).

SEKAM vs. Isokinetic Sample LOI

A comparison of the SEKAM readings, obtained by time averaging over the duration of the tests the signal to the DCS, with the LOI of the samples collected manually is shown in Figure 27. As shown, the SEKAM seemed to represent trends well during these tests, with the maximum errors occurring at the higher LOI values, which correspond to the tests at the lower excess O_2 levels (Tests 150-1, 151-1, and 151-4). It should be noted that the averaged readings obtained from the SEKAM were not compensated for delays or lags in sampling and analysis inherent in the system. Further testing of the SEKAM is planned in which (1) additional isokinetic samples will be collected and compared to the instruments outputs and (2) directly placing ash samples with known LOI levels into the sample collection cell for analysis.

CAM vs. Isokinetic Sample LOI

A comparison of the CAM readings, obtained by time averaging over the duration of the tests the signal to the DCS, with the LOI of the samples collected manually is shown in Figure 28. As with the SEKAM, the CAM unit appeared to represent trends well during these tests. As with the SEKAM, the CAM readings were not compensated for delays or lags in sampling and analysis. Further testing of the CAM is planned in which (1) additional isokinetic samples will be collected and compared to the instruments outputs and (2) directly placing ash samples with known LOI levels into the sample collection cell for analysis.

FOCUS vs. Isokinetic Sample LOI

One purpose of the tests conducted on July 20 and 21, 1995 was to provide calibration data for the FOCUS system. Because no ash sample is collected by this system, it must be calibrated using ash collected at either the precipitator inlet or hoppers. A plot comparing counts per minute to carbon-in ash levels as determined via isokinetic sampling is shown in Figure 29. Initially, Applied Synergistics supplied an equation that used the counts per minute from the FOCUS system along with unit load to estimate carbon-in-ash. These equations were later revised by Applied Synergistics to include excess O_2 in the formulation. The results of both these equations are shown in Figure 30. The inclusion of excess O_2 appeared to substantially improve the predictive value of the equation.

Time Response of the Carbon-in-Ash Monitors

When used for control and optimization, timeliness of the response is an important consideration when using the carbon-in-ash monitors. The response for each device is shown in Figure 31 for Tests 151-4, 5, and 6. As expected, the CAM system showed a faster response than the SEKAM primarily as a result of the reduced ash requirements of the former. As shown, the FOCUS did not respond to the changes in LOI brought on by excess O_2 level shifts. Subsequent to these tests, Applied Synergistics supplied a modified equation that incorporates excess oxygen, which improved the responsiveness of this instrument.

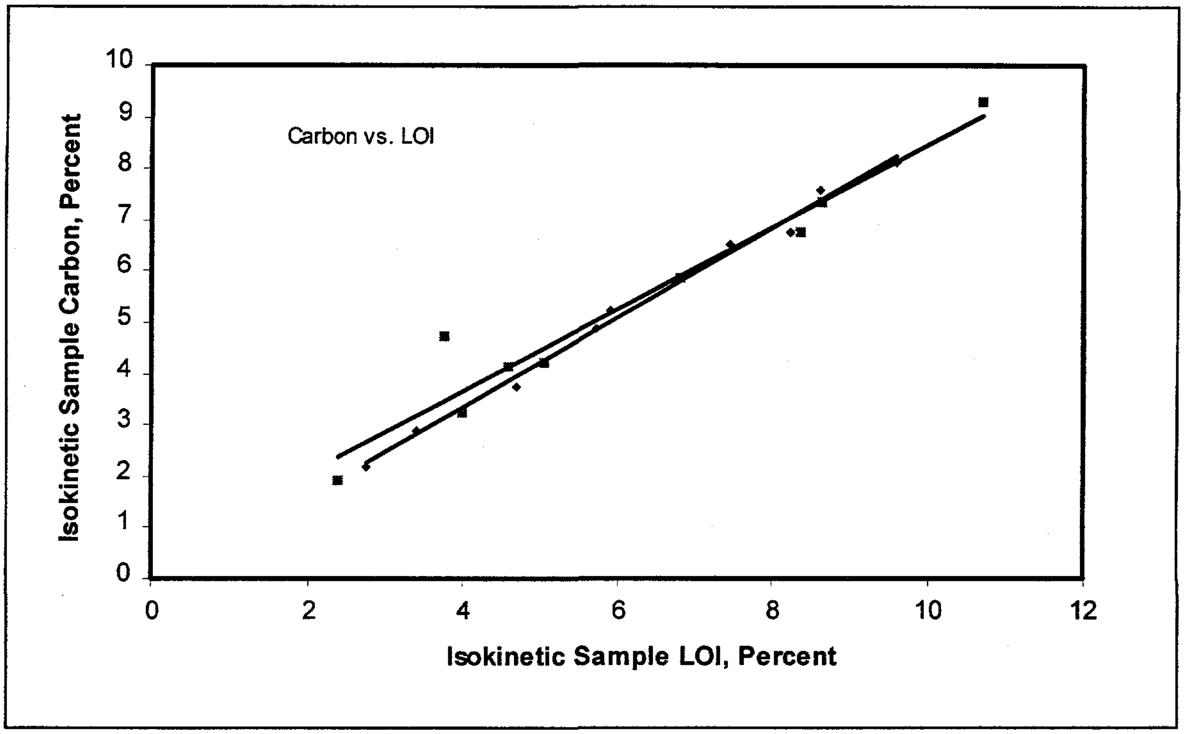


Figure 20: Carbon vs. LOI

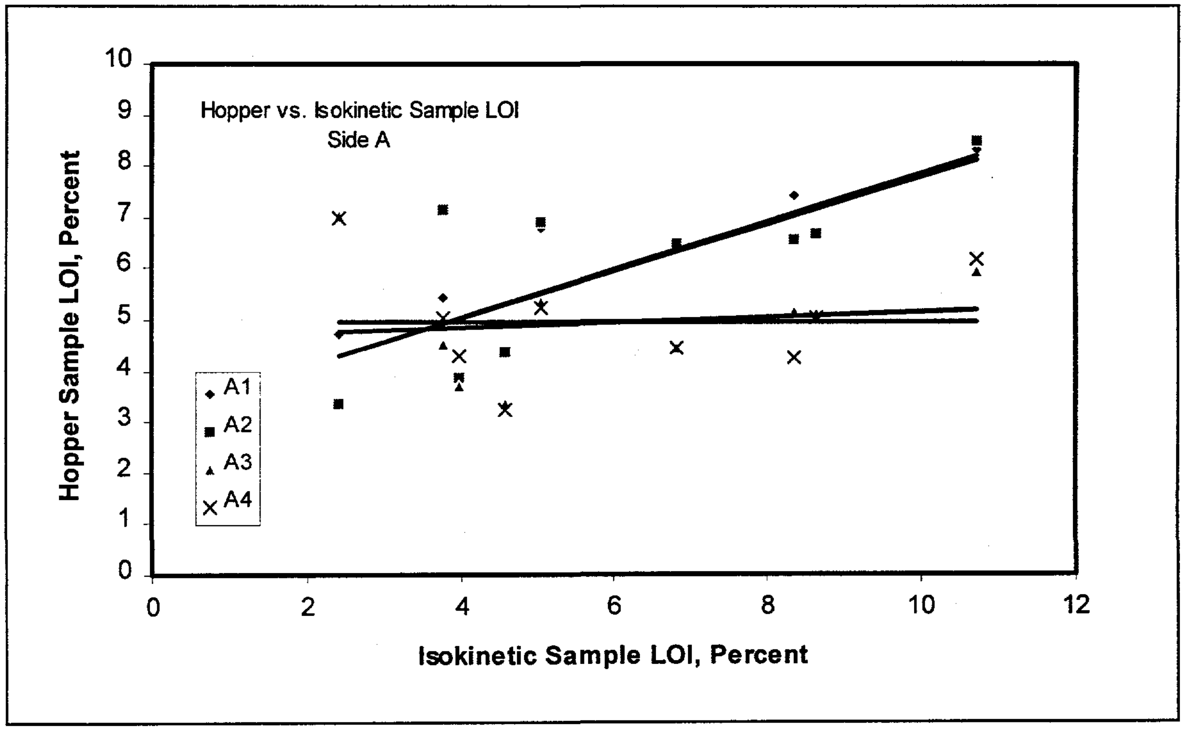


Figure 21: Hopper vs. Isokinetic Sample LOI - Side A - Individual Hoppers

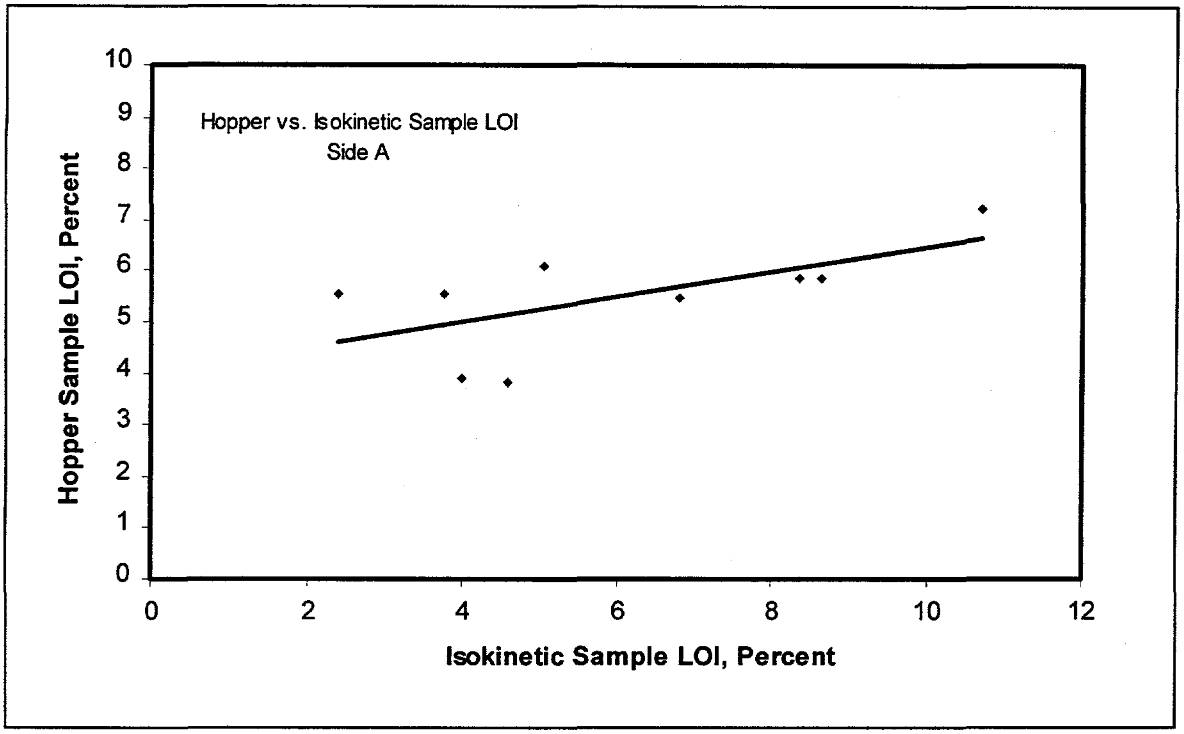


Figure 22: Hopper vs. Isokinetic Sample LOI - Side A

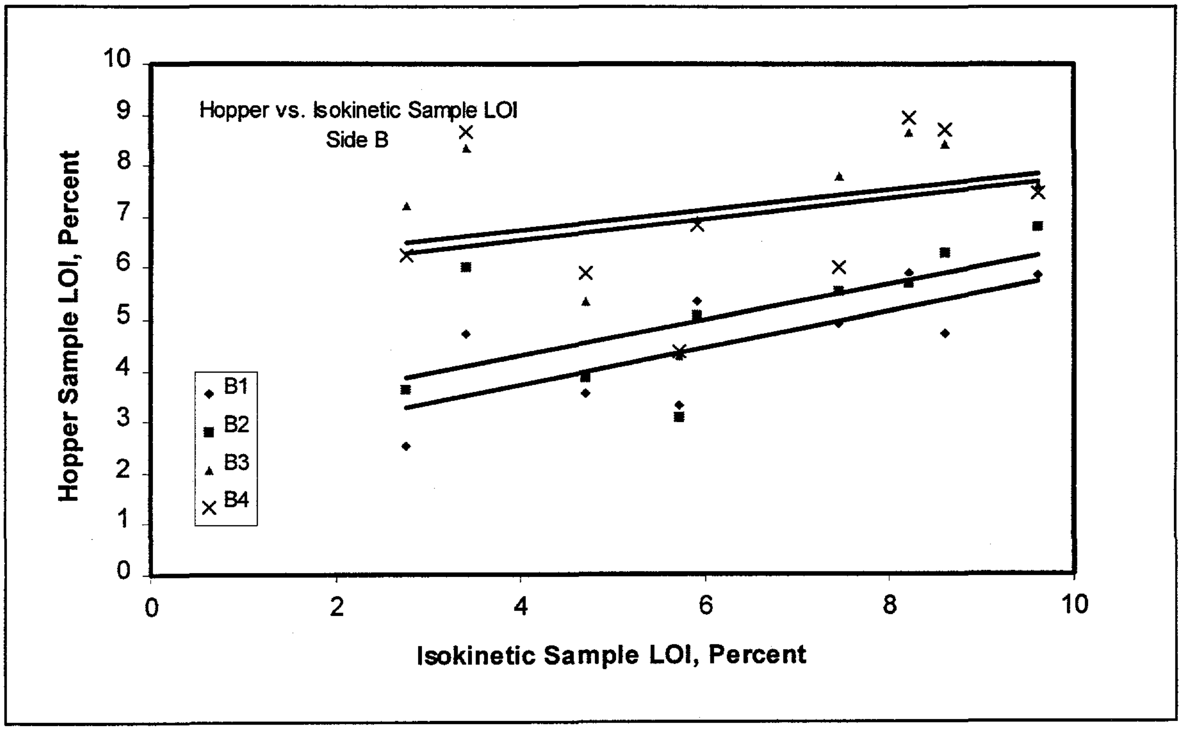


Figure 23: Hopper vs. Isokinetic Sample LOI - Side B - Individual Hoppers

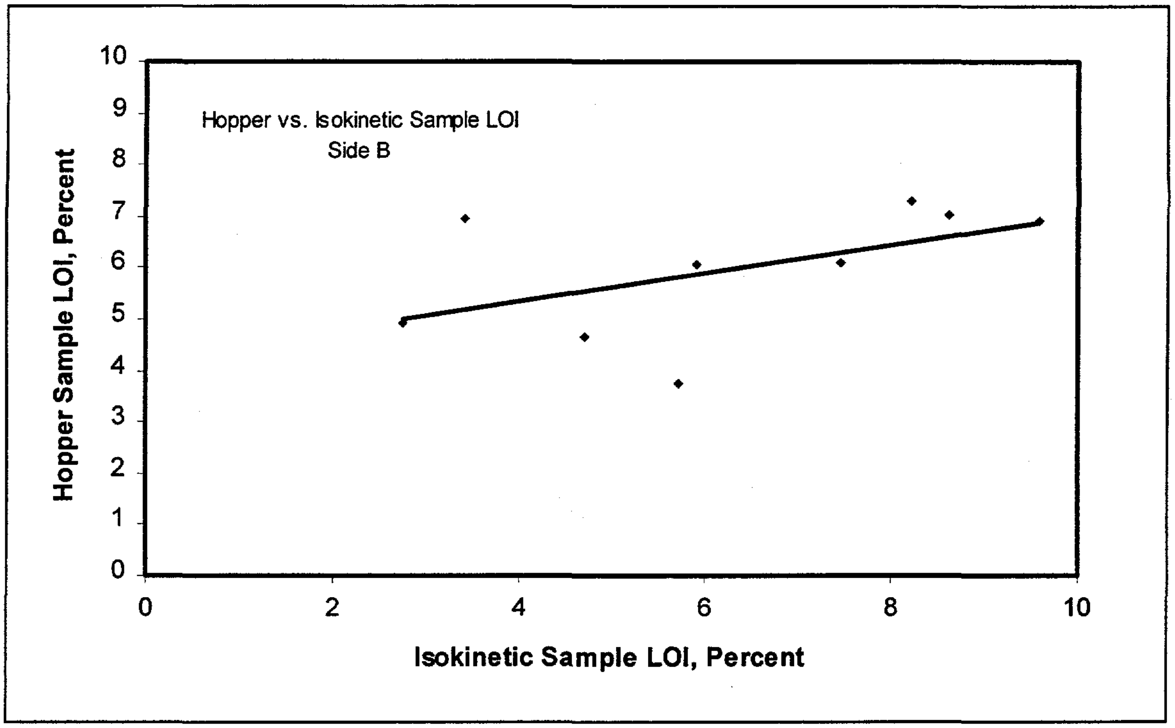


Figure 24: Hopper vs. Isokinetic Sample LOI - Side B

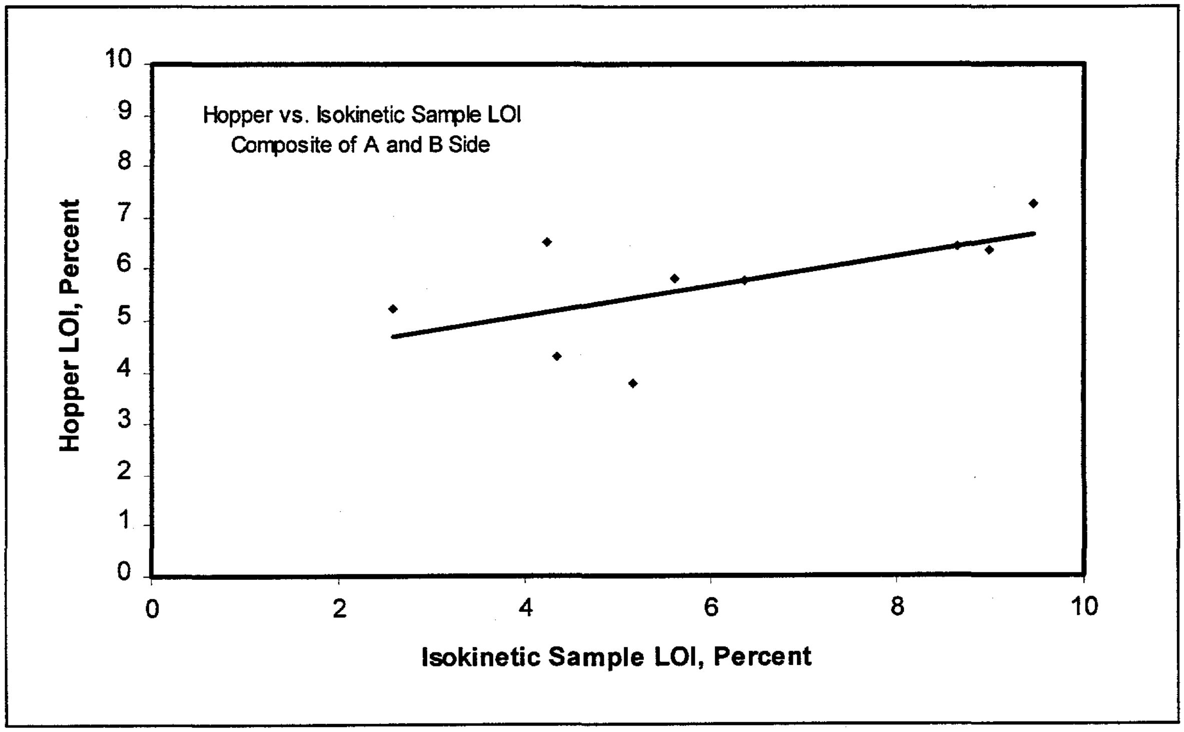


Figure 25: Hopper vs. Isokinetic Sample LOI - Side A and B

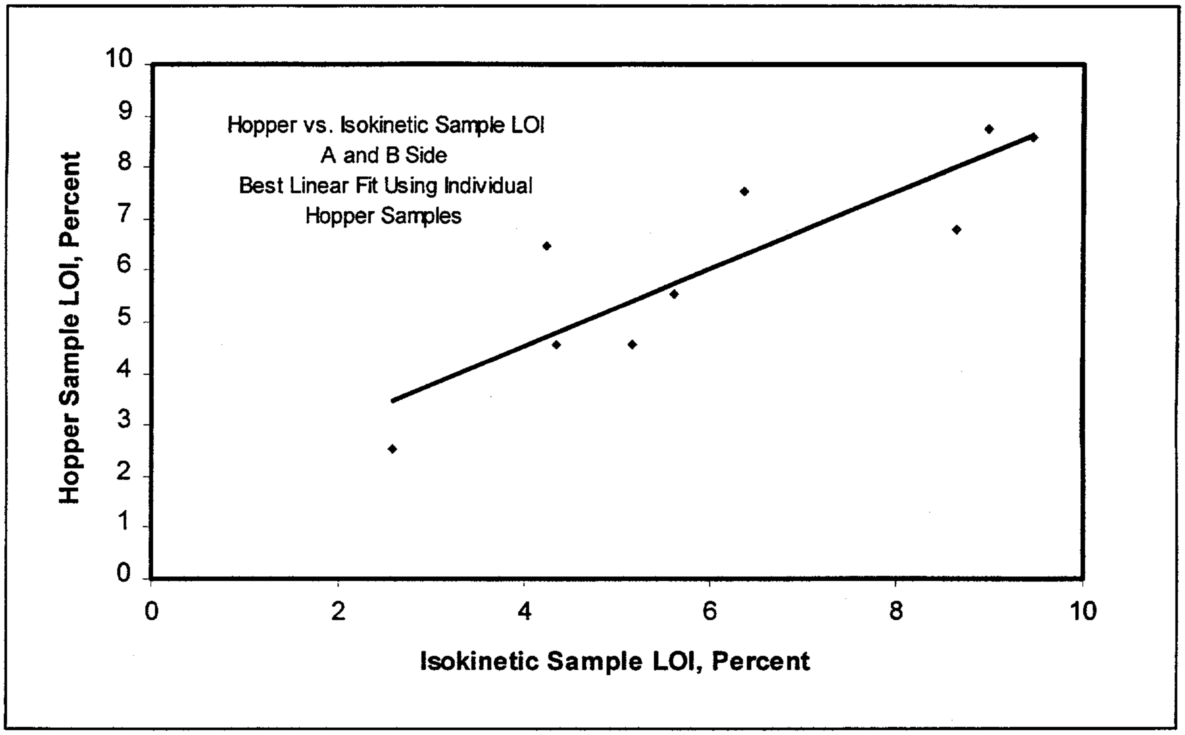


Figure 26: Hopper vs. Isokinetic Sample - Best Linear Fit

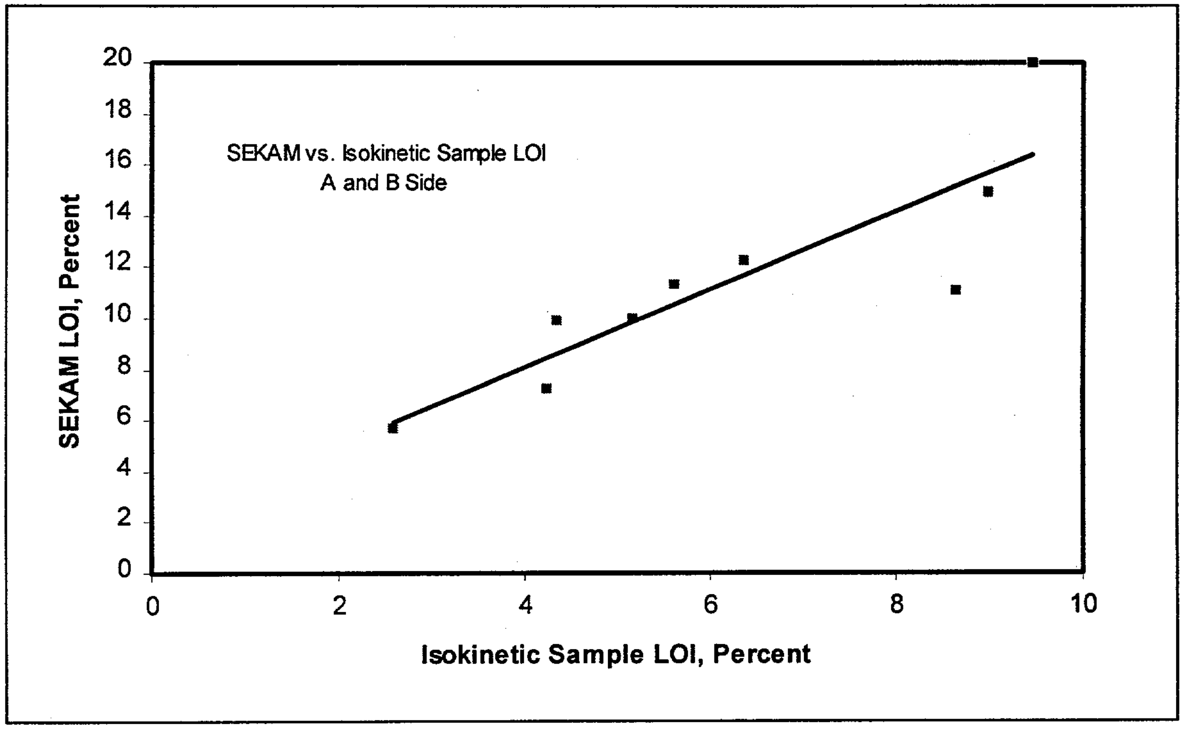


Figure 27: SEKAM vs. Isokinetic Sample LOI

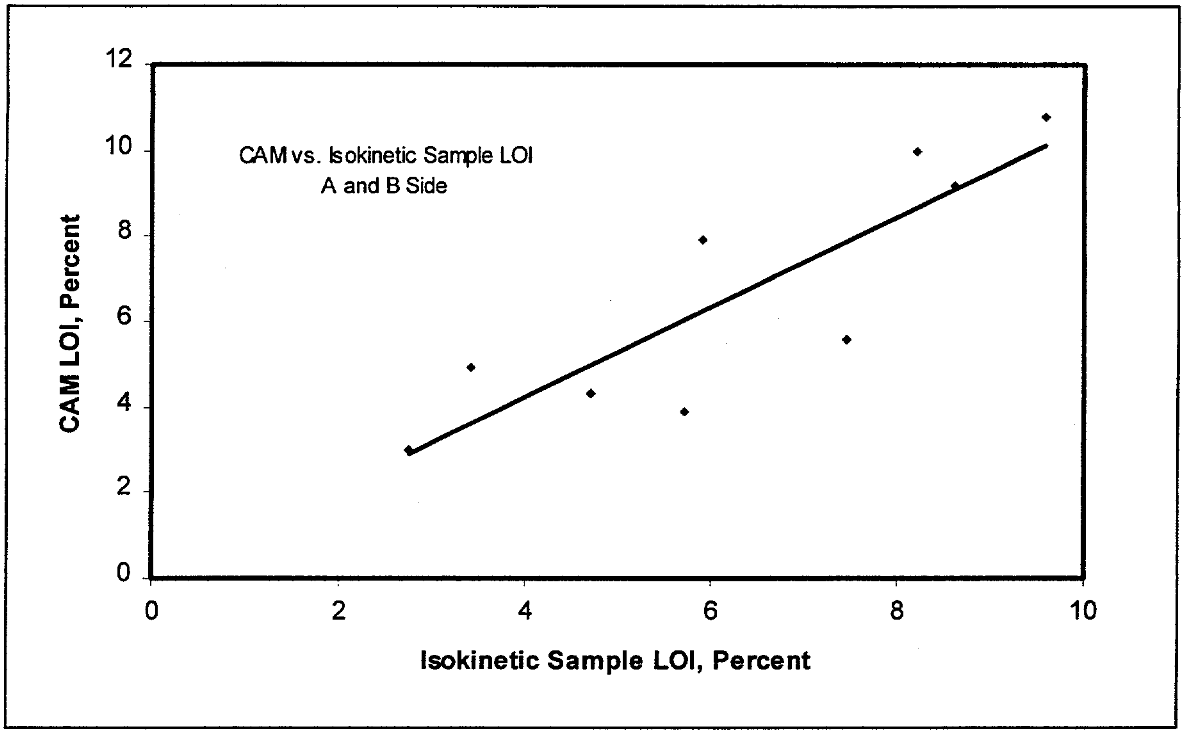


Figure 28: CAM vs. Isokinetic Sample LOI

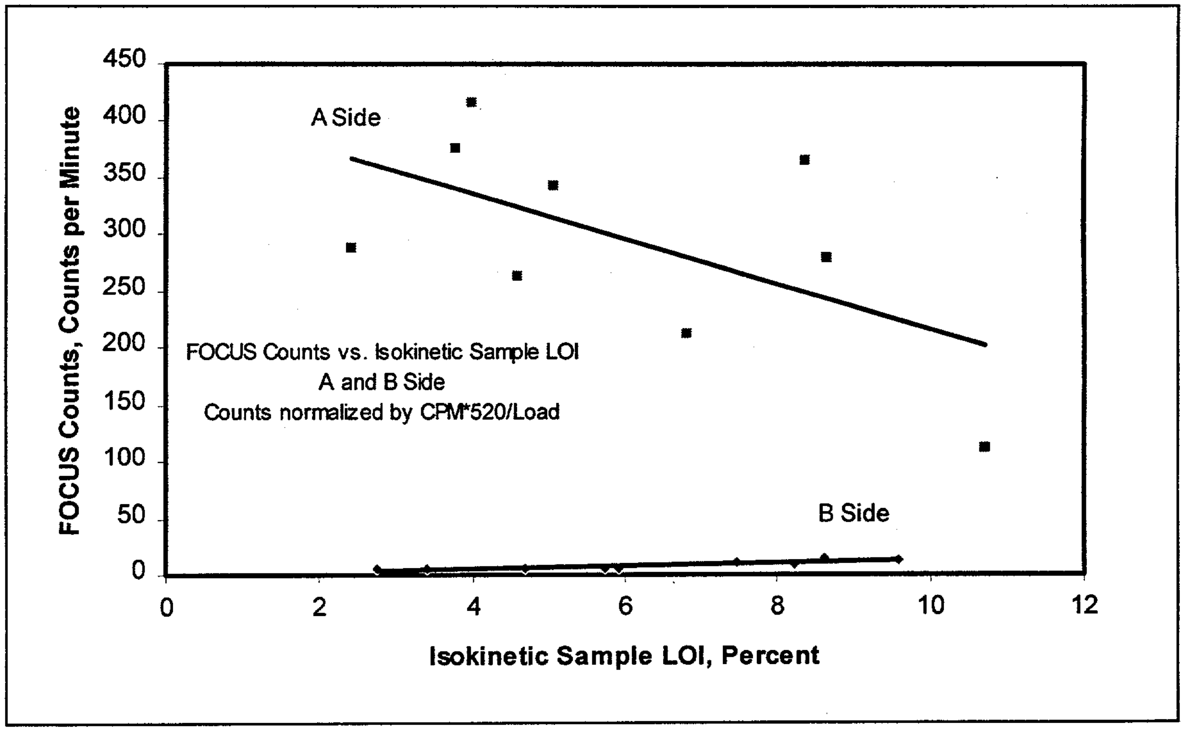


Figure 29: FOCUS Counts vs. Isokinetic Sample LOI

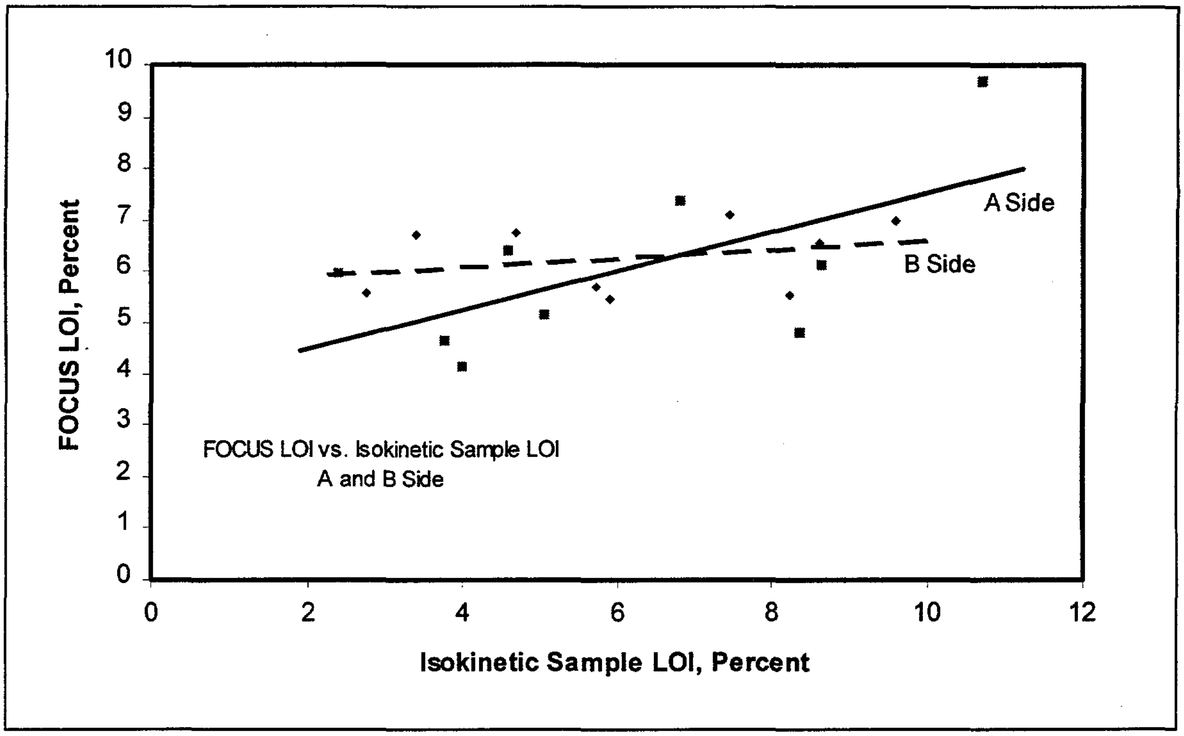


Figure 30: FOCUS LOI vs. Isokinetic Sample LOI

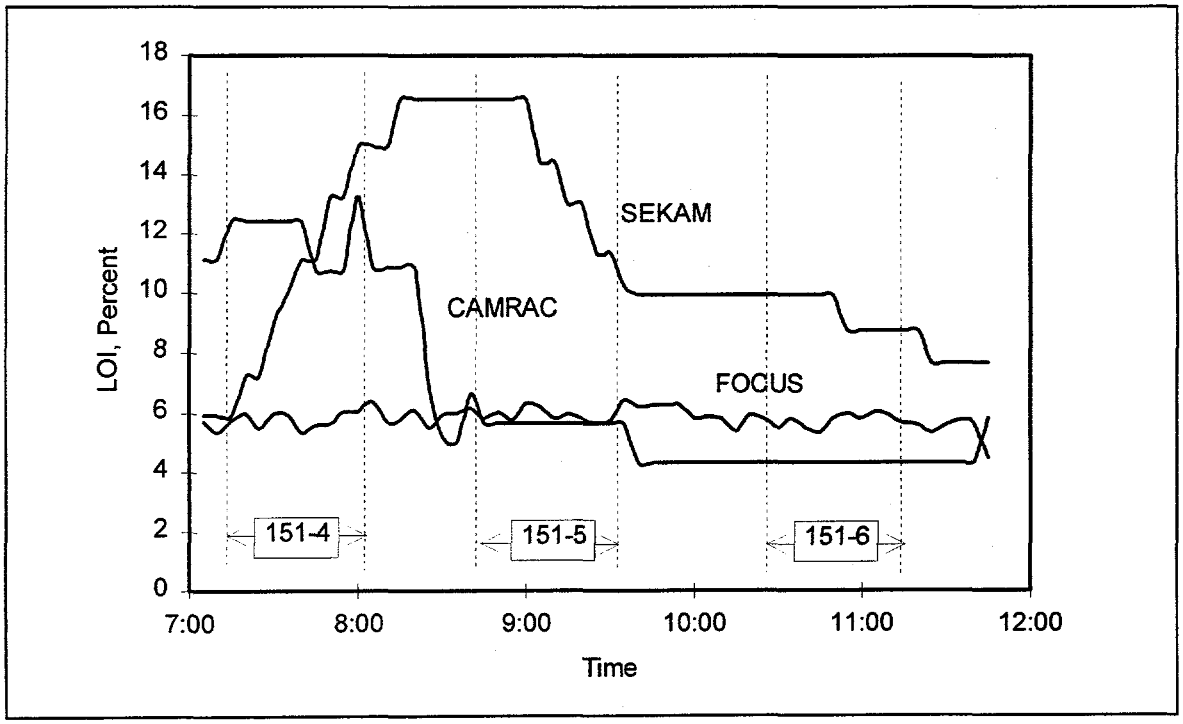


Figure 31: Carbon-in-Ash Monitors - Time Response

4. FUTURE PLANS

The following table is a quarterly outline of the activities scheduled for the remainder of the project:

Table 5: Future Plans

Quarter	Activity
Fourth Quarter 1995	• LOI Monitor Testing • Advanced Controls Testing • Final Reporting & Disposition
Fourth Quarter 1995	• Final Reporting & Disposition

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