On-Line Carbon-in-Ash Monitors

Survey and Demonstration

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EXECUTIVE SUMMARY

Fly ash unburned carbon (UBC) level is an important consideration for combustion efficiency as well as ash marketing. The presence of unburned carbon in fly ash has been shown to be a function of furnace design, coal quality, the ability of the pulverizer to grind the coal, and heat release rate. Boilers are designed to take these factors into consideration. However, the Clean Air Act Amendments of 1990 drove many utilities to switch coal supplies and install low NOx burners. Higher carbon-in-ash levels have been the result of these changes in coal quality and the staged combustion characteristics associated with low NOx burners. Over the past few years, several instruments for the on-line determination and monitoring of the unburned carbon content of ash samples have been developed. However, to date they have not been deployed widely in the U.S. despite potential uses for combustion optimization and as an aid in fly ash marketing.

Based on the lack of publicly available performance and operation data available for the current CIAM (carbon-in-ash monitor) commercial offerings, Southern Company initiated a demonstration of several commercial technologies on its coal-fired units. As part of a DOE Clean Coal Project demonstrating advanced wall-fired combustion techniques for the reduction on NO_x emissions from coal-fired boilers, the CAM, SEKAM and FOCUS systems were installed at Georgia Power Company's Plant Hammond Unit 4. CAM and M&W instruments were also placed at Alabama Power Company's Plant Gaston Unit 4. The testing of the instruments was conducted from November 1995 through August 1996.

A summary of the observations is as follows:

- CIAMs are, in general, useful for determining LOI trends.
- CIAMs are not particularly useful for determining absolute LOI levels.
- CIAMs are useful for on-line combustion optimization if consideration is given in the optimization methodology that the results obtained from the instrument are useful primarily for determining trends.

- Generally, the instruments are less reliable, less robust to changes in boiler operating conditions, and require more service than typical instrumentation found in power plants. If CIAMs are to be used successfully, a commitment must be made by plant staff to provide periodic maintenance to these instruments, possibly on a weekly or monthly basis.

- The relatively high capital and maintenance costs of the current commercial offerings are a major hindrance to further deployment, especially in view of (1) reliability and accuracy concerns and (2) the perception that these instruments are more of a luxury than a necessity. These costs vary greatly from instrument to instrument.

- Follow-up vendor support is a concern. Many of these instruments are from relatively small companies or from companies who do not have service representatives domestically. Also, because in general the CIAMs are produced in extremely low quantities, there is a tendency for the vendors not to keep spare parts in inventory. Another factor is that for a number of vendors, the CIAMs continue to evolve, leading to one-of-a-kind installations.

Many of the above support problems may be resolved once there is a large user base in the U.S. However, at this time no manufacturer has an installed base of greater than 10 instruments in the U.S. A positive factor is that the vendors continue to improve their products while other technologies are planned for commercialization in the near future.

Although the demonstration program was not intended as a competition between vendors, a byproduct of the side-by-side testing is that some comparisons of this nature can be made. Based on the testing at Gaston and Hammond, no CIAM was superior to the other monitors in all performance categories, although performance for some instruments was better in an overall sense. This performance is based on testing at these two sites only and may not be indicative of the performance of these CIAMs at other sites

ABSTRACT

Fly ash unburned carbon (UBC) level is an important consideration for combustion efficiency as well as ash marketing. The presence of unburned carbon in fly ash has been shown to be a function of furnace design, coal quality, the ability of the pulverizer to grind the coal, and heat release rate. Boilers are designed to take these factors into consideration. However, the Clean Air Act Amendments of 1990 drove many utilities to switch coal supplies and install low NOx burners. Higher carbon-in-ash levels have been the result of these changes in coal quality and the staged combustion characteristics associated with low NOx burners. Over the past few years, several instruments for the on-line determination and monitoring of the unburned carbon content of ash samples have been developed.

Several of these instruments were installed on Southern Company sites for evaluation. As part of a DOE Clean Coal Project demonstrating advanced wall-fired combustion techniques for the reduction on NOx emissions from coal-fired boilers, the CAM, SEKAM and FOCUS systems were installed at Georgia Power Company's Plant Hammond Unit 4. CAM and M&W instruments were also placed at Alabama Power Company's Plant Gaston Unit 4. This report describes the technologies installed and tested as part of these programs. Aspects addressed include operational method, response time, instrument size, portability of the apparatus, sample size, accuracy, cost and normal maintenance requirements. To a large degree, this information is taken from material supplied by these vendors. Performance data from these sites is presented. Accuracy of carbon measurement, availability, response time, and durability are some of the issues addressed.

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FOCUS

RCA

SEKAM

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LIST OF ABBREVIATIONS AND ACRONYMS

ASME	American Society of Mechanical Engineers
C	carbon
CIA	carbon-in-ash
CIAM	carbon-in-ash monitor
CAA(A)	Clean Air Act (Amendments)
CO	carbon monoxide
DAS	Data acquisition system
DCS	Digital control system
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	electrostatic precipitator
kw	kilowatt
LNB	low NO_x burner
LOI	loss on ignition
(M)Btu	(million) British thermal unit
MOOS	Mills out of service
MW	megawatt
NO_x	nitrogen oxides
O, O_2	oxygen
psig	pounds per square inch gauge
PTC	Performance Test Codes
RSD	relative standard deviation
SCS	Southern Company Services
UBC	unburned carbon
VM	volatile matter

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Thanks go out to the Plant Hammond and Plant Gaston staff and in particular Ernie Padgett (Hammond), Carzell Walton (Gaston), and Steve Howe (Gaston) for their gracious toleration of our frequent requests and for allowing their unit to be used in the testing of these technologies.

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Peter Wilson – former representative of Clyde Pneumatic

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INTRODUCTION

Electric utilities are the single largest user of coal in the United States. During 1995, of the approximately 1 billion tons of coal consumed in the United States, approximately 829 million tons were used by the utility industry (EIA, 1995). This consumption represents approximately 1.7×10^6 GWHR of electrical generation or nearly 50% of total U.S. generation. Coal consists principally of carbon with smaller amounts of combustibles and non-combustibles. Ash consists of the solid components from the complete combustion of coal and is composed mainly of the oxides formed from the mineral constituents of coal. The amount of ash produced per unit of coal combusted is dependent on the type of coal but can vary from 1% to more than 20%, averaging nearly 10% for the coal used by the US utility industry in 1995 (EIA, 1995). As a result of incomplete combustion, unburned carbon is also a component of the solid by-products of combustion.

Fly ash unburned carbon (UBC) level is an important consideration for combustion efficiency as well as ash marketing. The presence of unburned carbon has been shown to be a function of furnace design, coal quality, the ability of the pulverizer to grind the coal, and heat release rate. Boilers are designed to take these factors into consideration. However, the Clean Air Act Amendments of 1990 drove many utilities to switch coal supplies and install low NOx burners. Higher carbon-in-ash levels have been the result of these changes in coal quality and the staged combustion characteristics associated with low NOx burners (EPRI, 1993).

Based upon a 1% LOI reduction in the ash produced by a 1000 MW electric generating station, a monetary value can be associated with the benefits from on-line monitoring (Table 1-1).

Table 1-1
Direct Fuel Loss Savings by Reducing LOI by 1%

Average Heat Value of Coal	12000 Btu/lb
Average Cost of Coal	$1.50 / Million Btu
Ash Production	255,000 tons
Fuel Value Gained	$91,500 / year

Figure 1-1 generalizes this type of information. This plot shows the money lost each year based upon the plant generating capacity and common LOI characteristics of the ash produced at the site. An average coal heating value of 12,000 Btu / lb, average heat rate of 10,000 Btu / kWh, and an average coal cost of $1.50 / MBtu were assumed for use in the calculations. Calculations were completed based upon plants burning coal with 10% ash. The calculations were performed at 100 MW intervals for a range of plant generating capacity up to 3500 MW.

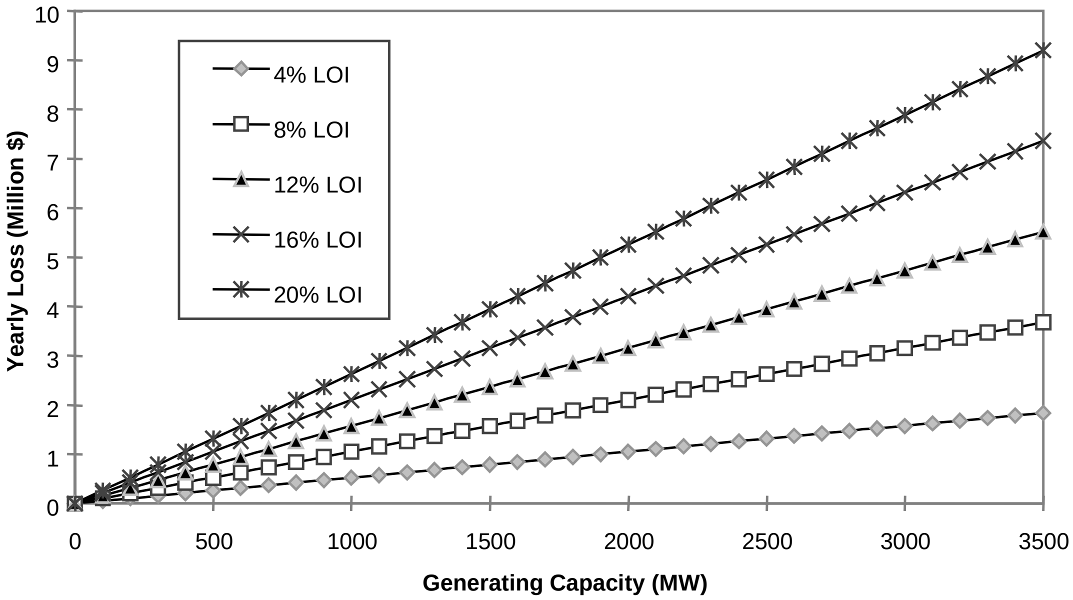

Figure 1-1
Cost of LOI

In addition to the direct fuel loss, there can also be an economic loss if the utility is unable to sell the ash. Utilities sell fly ash whenever possible, but there are usually carbon content limits on fly ash quality specifications. Some utilities operate very close to the fly ash carbon content limit as a result of the need to control NOx to a certain value. Table 1-2 illustrates the magnitude of cost savings that can be attained if fly ash is sold compared to being disposed. For example, consider a 400 MW boiler operating at the conditions shown in the footnotes of Table 1-2. The table shows that the annual costs of handling fly ash is $280,000 if 80 percent is disposed at a cost of $4 per ton and 20 percent is sold at $2 per ton. The annual cost is $40,000 if 40 percent is disposed and 60 percent is sold. The differential is $240,000 and would represent the annual savings that could be obtained if 40 percent of the fly ash being disposed could be moved to the sales category. As evidenced by the above cost considerations, UBC levels can have a significant impact on the cost of unit operation.

Table 1-2
Annual Costs of Fly Ash Disposal Less Fly Ash Sales

Unit Capacity	Percent Fly Ash Disposal / Percent Fly Ash Sales					
MW	0/100	20/80	40/60	60/40	80/20	100/0
200	-99,000	-40,000	20,000	79,000	139,000	198,000
400	-198,000	-79,000	40,000	159,000	280,000	397,000
600	-298,000	-119,000	60,000	238,000	417,000	595,000
800	-397,000	-159,000	79,000	317,000	555,000	793,000
1,000	-496,000	-198,000	99,000	397,000	694,000	992,000

ASSUMPTIONS:
65% Capacity Factor
10% of the coal is fly ash
$2 per ton sales price for fly ash
$4 per ton disposal cost for fly ash
23 MBtu per ton coal

On-line performance optimization of the combustion process requires a timely and reliable response. Presently, most utilities monitor fly ash UBC levels by manually obtaining fly ash samples from the precipitator ash hoppers or flue gas streams and sending the samples to a laboratory for analysis. Depending on the laboratory analysis procedure employed, the results of the analysis may not be available for up to 24 hours. This rather long delay can significantly hinder the combustion optimization process. Another problem associated with sampling is the difficulty assuring that the sample analyzed is representative of specific boiler parameters. If the sample is not representative, its analysis will not provide a true indication of the combustion conditions in the furnace. In some cases, utilities rely on carbon monoxide levels to indicate combustion performance and to provide an alert for potential combustion problems. For instance, a higher than normal carbon monoxide level may result from inadequate fuel/air distribution. However, increased CO levels are not always a precursor for higher UBC levels.

Over the past few years, several technologies for the on-line determination and monitoring of the unburned carbon content of ash samples have been developed (Figure 1-2). Infrared, capacitance, and microwave-based systems are some of the technologies that have been developed to aid in the on-line monitoring of unburned carbon content in ash. Several of the systems marketed to date include units from CAMRAC, Clyde-Sturtevant, Applied Synergistics, M&W Asketeknik, and Rupprecht & Patashnick, Co.

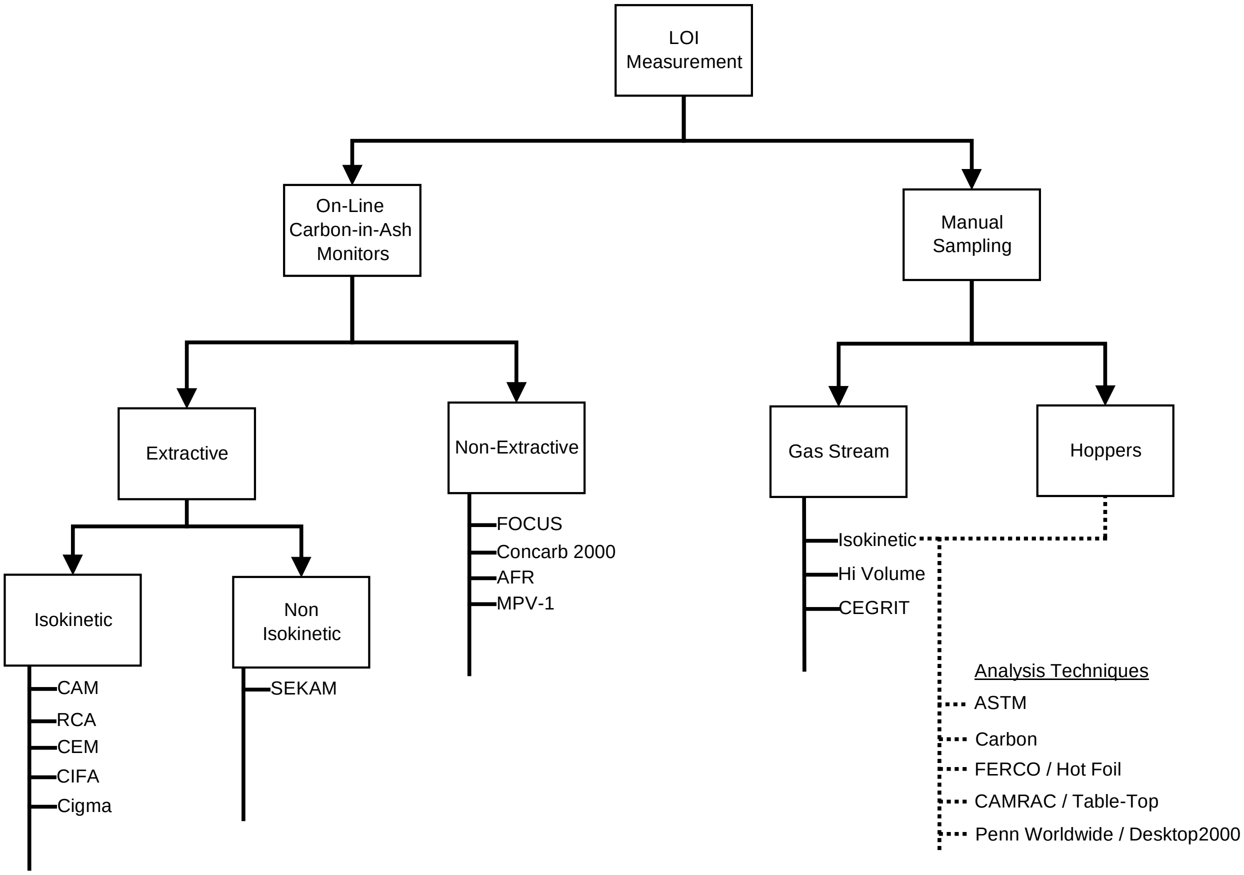

Figure 1-2
LOI Measurement Methods

Several of these instruments were installed on Southern Company sites for evaluation. As part of a DOE Clean Coal Project demonstrating advanced wall-fired combustion techniques for the reduction on NO_x emissions from coal-fired boilers, the CAM, SEKAM and FOCUS systems were installed at Georgia Power Company's Plant Hammond Unit 4. CAM and M&W instruments were also placed at Alabama Power Company's Plant Gaston Unit 4. This report provides background and an overview of technical issues involved with on-line monitoring of UBC. The primary focus is, however, the test program conducted at Southern Company sites. Descriptions of the technologies installed and tested as part of these programs are provided, along with results of the testing. Aspects addressed include operational method, response time, instrument size, portability of the apparatus, sample size, accuracy, cost and normal maintenance requirements. To a large degree, this information is taken from material supplied by these vendors. Performance data from these sites is presented. Accuracy of carbon measurement, availability, response time, and durability are some of the issues addressed.

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BACKGROUND AND TECHNOLOGY OVERVIEW

Fly ash unburned carbon (UBC) level is an important consideration for combustion efficiency as well as ash marketing. The presence of unburned carbon in fly ash has been shown to be a function of furnace design, coal quality, the ability of the pulverizer to grind the coal, and heat release rate. Boilers are designed to take these factors into consideration. However, the Clean Air Act Amendments of 1990 drove many utilities to switch coal supplies and install low NOx burners. Higher carbon-in-ash levels have been the result of these changes in coal quality and the staged combustion characteristics associated with low NOx burners.

On-line performance optimization of the combustion process requires a timely and reliable response. Presently, most utilities monitor fly ash UBC levels by manually obtaining fly ash samples from the precipitator ash hoppers or flue gas streams and sending the samples to a laboratory for analysis. Depending on the laboratory analysis procedure employed, the results of the analysis may not be available for up to 24 hours. This rather long delay can significantly hinder the combustion optimization process. Another problem associated with sampling is the difficulty assuring that the sample analyzed is representative of specific boiler parameters. If the sample is not representative, its analysis will not provide a true indication of the combustion conditions in the furnace. In some cases, utilities rely on carbon monoxide levels to indicate combustion performance and to provide an alert for potential combustion problems. For instance, a higher than normal carbon monoxide level may result from inadequate fuel/air distribution. However, increased CO levels are not always a precursor for higher UBC levels.

Technology Issues and Factors

Many technical issues and factors affect the use of CIAMs. These issues and factors are discussed briefly in the following paragraphs.

Extractive vs. Non-Extractive

CIAM technologies fall into two broad categories: extractive and non-extractive systems. Extractive systems remove fly ash from the flue gas stream and perform the analysis whereas non-extractive systems infer the UBC level from measurements directly on the flue gas stream. Both type systems have their relative merits, a summary of which is provided in Table 2-1.

Table 2-1
Relative Merits of Extractive and Non-Extractive CIAMs

Characteristic	Extractive	Non Extractive	Comments
Timeliness of reading		+	Fly ash sample not required for non-extractive systems typically make these systems have a faster response.
Verifiable accuracy / calibration	+		The accuracy of an extractive system can be verified relatively easily by either (1) placing ash of known carbon content into the instrument or (2) performing a carbon analysis on an ash sample collected from the instrument. In general, to verify the performance of a non-extractive system, a fly ash sample must be collected using isokinetic or high volume sampling.
Spatial resolution	+		Multi-point, extractive systems may provide information concerning UBC distribution across the duct. This information can be useful for diagnosing combustion problems.
Hardware reliability		+	Automatic fly ash sampling can be problematic and are the source of most failures in an extractive system.
Ease of installation		+	Non-extractive systems do not require an ash sampling system.
Spatial averaging		+	Non-extractive systems provide an average UBC level for the duct – this is typically what is needed.
Closer to Primary Analysis	+		Extractive systems generally have a firmer foundation in providing a correlation between the measured variable (such as microwave absorption) and UBC.

+ Relative positive

Timeliness of the Analysis

An important issue with all CIAMs is their ability to obtain timely readings of the UBC level. If CIAMs are to be used to optimize combustion performance, the results must be reflective of the current operating conditions of the boiler. Depending on the technology utilized, load, and ash content of the coal, the overall time to obtain a UBC reading ranges from approximately one minute to over two hours. Because boiler operating conditions may change substantially over a period of a few minutes (especially when the unit is operating in economic dispatch), the difficulty in correlating UBC to boiler operating modes is greatly reduced if the total time response of the CIAM is less or on the same order of magnitude as that of the furnace. If this is not the case, meaningful results are largely dependent on the unit remaining at steady state conditions for extended periods of time.

Equipment Reliability and Maintenance Requirements

In general, the current offering of commercial CIAMs, in particular the extractive type, are complex instruments which, when compared to other typical plant instrumentation, requires considerable effort by plant staff to maintain. Given that many plant staffs are being reduced and the workload of the remaining staff has been increased, there is a tendency to focus on maintaining instrumentation that is required for unit operation and not instruments that provide added value, such as CIAMs. If CIAMs are to be used successfully, a commitment must be made by plant staff to provide periodic maintenance to these instruments, possibly on a weekly or monthly basis.

Dependence of the UBC Reading on Coal Properties and Furnace Conditions

Depending on the technology employed, the accuracy of a CIAM may depend on plant operating conditions. Factors that may affect the accuracy of the instrument include (excluding spatial stratification errors):

Extractive Systems

- Change in coal characteristics affects the calibration of some instruments.

Non-Extractive Systems

- Change in coal characteristics affects the calibration of some instruments.
- Temperature and oxygen profile variations in the furnace as the result of a change in operating mode (load, excess oxygen, mills-in-service, overfire air levels, tilt position, etc.) or slagging characteristics.

Representativeness of the Ash Sample

In order for any of the CIAMs to perform accurately, the instrument must:

- Extractive systems - collect a representative fly ash sample.
- Non-extractive systems – have a representative view of the flue gas stream.

Many factors affect the capability of the instrument to obtain or view a representative sample.

Single Point vs. Multiple Point Sampling

A CIAM is typically installed with the goal of estimating the average UBC/LOI level of the fly ash exiting the furnace. However, the flue gas stream emanating from a coal-fired boiler is very heterogeneous as a result of combustion non-uniformity and flow path obstructions. This heterogeneity extends to both the particle and gas characteristics. As a result of this spatial variation, sampling at multiple points is likely to improve overall accuracy of the measurement and, dependent on the CIAM capabilities, provide a method to determine gas velocity, ash loading, and UBC variations across the duct.

The degree to which a multi-point system would improve the overall accuracy of the system is dependent on several factors including:

- Degree of spatial variation of UBC, ash loading, and gas velocity (which affects the rate at which fly ash is collected) across the duct.
- Changes in the spatial variation with load and other operating factors such as excess oxygen, furnace heat transfer characteristics, burners-in-service, tilt position, etc.
- The number of probes utilized in the multi-point system.
- Impact of the multi-point sampling on the time required to collect and perform the analysis of the ash samples.

In general, multiple point sampling increases the likelihood of obtaining an accurate UBC/LOI measurement – albeit at the cost of added complexity, expense, and possibly overall sampling rate. For non-continuous particulate measurements, ASME, EPA, and others have defined standards for the number and placement of sampling probes when collecting particulate from the flue gas stream [EPA, 1991][ASME, 1980]. For the ASME and EPA standards, the minimum number of grid points is 12 for utility sized ducts under ideal conditions. The number of grid points increase substantially (up to 25 for the case of the EPA method) when there are flow disturbances either upstream or downstream of the sampling plane. The number and placement of the probes are based on several studies conducted by these organizations. Because of cost and other considerations, this number of sample points is not feasible on CIAMs.

Gas Velocities

Flue gas velocity profiles have been studied by numerous organizations. Results from an EPA funded study is shown in Figure 2-1 [EPA, 1982]. This study consisted of characterizing the flow in 21 rectangular ducts in large power plants (> 100 MW). As shown, when one probe was utilized, an average gas velocity error of approximately 15% was obtained. An assumption of this study was that there was no a priori knowledge of the flow distribution and the probes were placed at the centroids of equal rectangular elemental areas. Thus for one probe, it would be placed at the center of the duct. To decrease the error to less than 5% with a 95% confidence level, more than four probes per duct would be required (Figure 2-1). EPRI has also reported the "typical" normalized standard deviation of the gas velocity at the precipitator inlet is 0.25 [EPRI, 1987]. Using this estimate, for a mean, full-load duct velocity of 80 fps, the flow standard deviation is 20 fps. Therefore, assuming the velocity data is normally distributed, the probability of randomly selecting a sampling location with a velocity within ±5% of the mean is 15%. The 95% confidence range is approximately ±49% (±39 fps), very similar to what was observed in the EPA study.

An example gas velocity distribution is shown in Figure 2-3 for a 500 MW coal-fired unit [SCS, 1997]. Data shown are for three tests at two loads (500 and 400 MW). The left side of the figure shows the actual velocity distribution whereas the right shows the ratio of the velocity to the mean velocity. Figure 2-4 shows the area of the duct where a single point measurement would represent the mean velocity within ±5% for each of the three tests. The area represents approximately 16% of the total duct area.

Particulate Mass Rate

Particulate mass rate is more directly related to the determination of the average duct UBC than gas velocities. During the 1970's, EPA sponsored work to determine typical particulate distributions [EPA, 1982]. As shown in Figures 2-5 and 2-6, the average relative error and the 95% confidence range for a single probe installation were approximately 20% and 40%, respectively. For a four-probe installation, these figures would drop to approximately 5 and 10%, respectively. Superimposed on these plots is data from more recent testing on an 860 MW, tangential-fired unit [DiGioia, 1996]. As seen from this figure, the data generally falls within the range presented by the earlier study. Also, note that for at least one case, a single probe at the center of the duct would have produced a reading more representative of the duct average than a system with two or four probes.

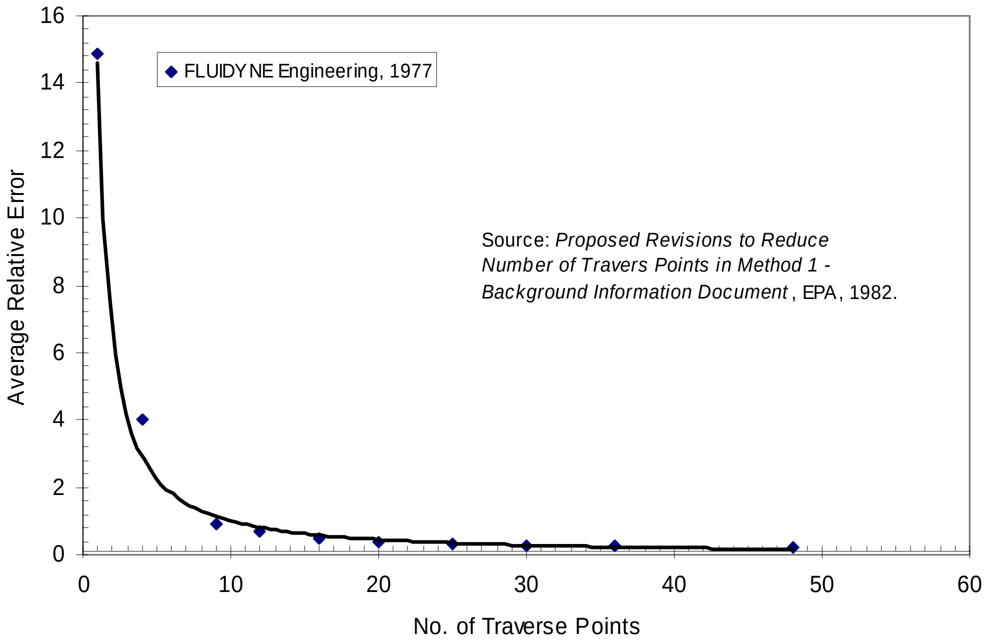
UBC and LOI

In addition to gas velocity variations, UBC (LOI) also varies across the duct. Variations in UBC have been studied much less than gas velocity and mass loading. An example of an LOI distribution is shown in Figure 2-7 [Tisch, 1990]. For the 85 MW tangential-fired unit, in the "A" duct, LOI varied from 1.9% to 3.6% while in the "B" duct, LOI varied from 1.3% to 3.6%. The average LOI for the "A" and "B" ducts were 2.9% and 2.6%, respectively. The relative standard deviation (RSD) for the "A" side was 0.17 while the "B" side was 0.25. This RSD is similar to what has been reported for gas velocity and mass loading. The ratio of LOI to average LOI is shown in Figure 2-8. The isoclines show the degree of error of a single point measurement. The regions of the ducts (approximately 20% of the total area) that would provide a reading within ±5 percent of the average LOI is shown in Figure 2-9. Similar results have been reported elsewhere [DiGioia, 1996][Eskenazi, 1989]. Another consideration is that since fly ash mass loading varies across the duct, when determining the duct average UBC, the UBC readings at each probe location should be weighted by the amount of fly ash collected over the sampling period at that location [DiGioia, 1996][ASME, 1980]. For example, the duct average UBC should be calculated as follows:

$$UBC_{avg} = \frac{UBC_i \times M_i}{M_i}$$

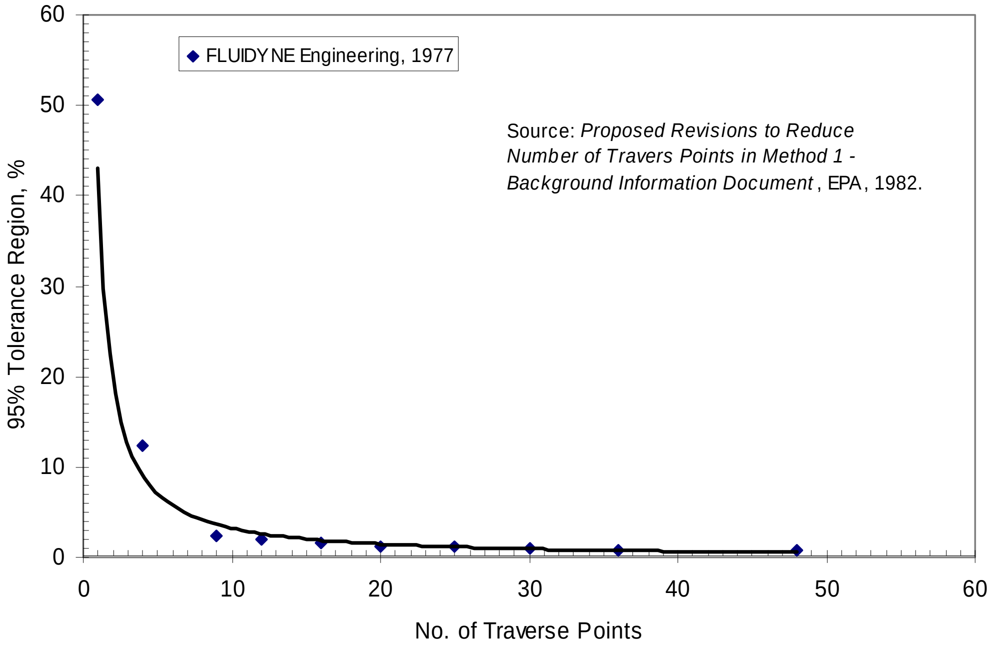
where M_i and UBC_i are the fly ash mass collected during the sample period and UBC level at a given location.

Although the above data makes a strong case for a multiple probe installation, according to the type of CIAM, this could add substantially to the cost of the installation. Even if duct surveys are performed to locate CIAM probes, there is no guarantee that a representative sample location selected for one nominal operating condition will be the same for subsequent tests under different or even the same operating conditions [Eskinazi, 1989]. While the absolute error of the UBC obtained from a single point or CIAM may be large, these systems with one or two probes can be useful in reflecting UBC trends [Eskinazi, 1989][SCS, 1997].



Source: *Proposed Revisions to Reduce Number of Travers Points in Method 1 - Background Information Document*, EPA, 1982.

Figure 2-1
Average Relative Errors in Velocity as a Function of Number of Traverse Points



Source: *Proposed Revisions to Reduce Number of Travers Points in Method 1 - Background Information Document*, EPA, 1982.

Figure 2-2
Confidence Interval in Velocity as a Function of Number of Traverse Points

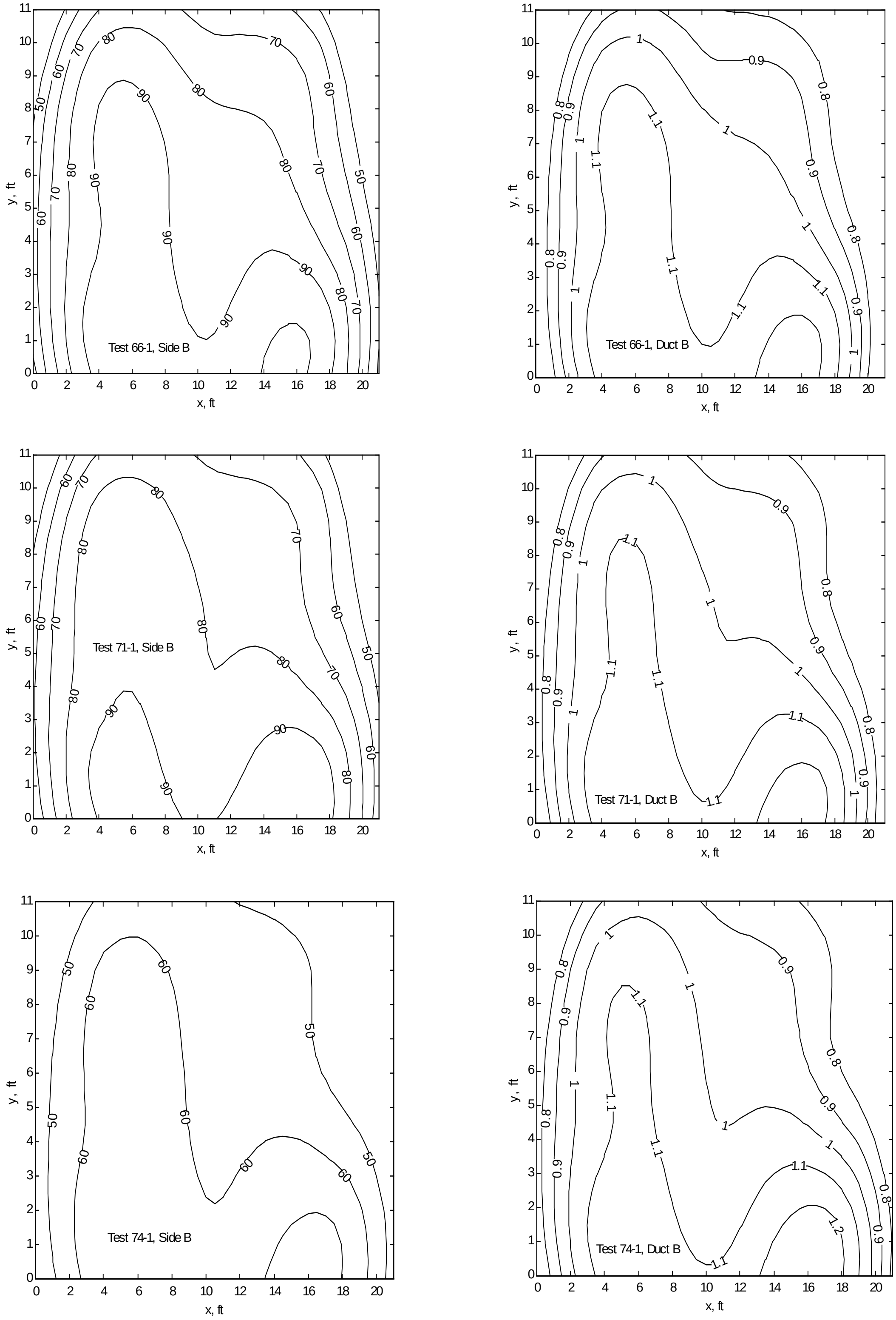


Figure 2-3
Velocity Mapping for a 500 MW Wall-Fired Unit.

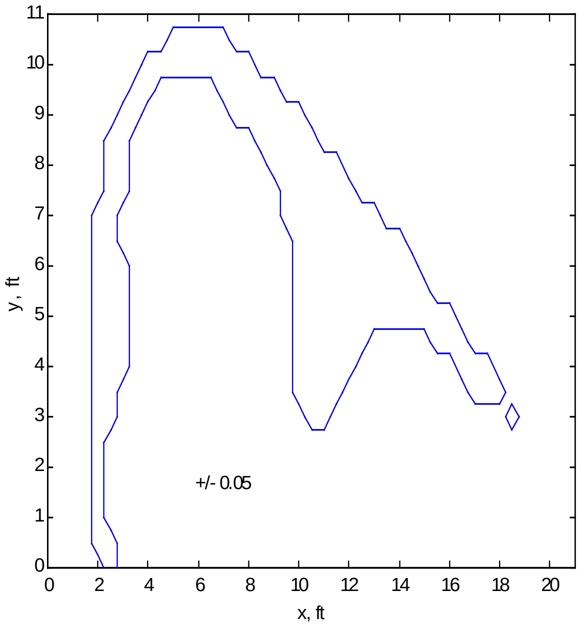
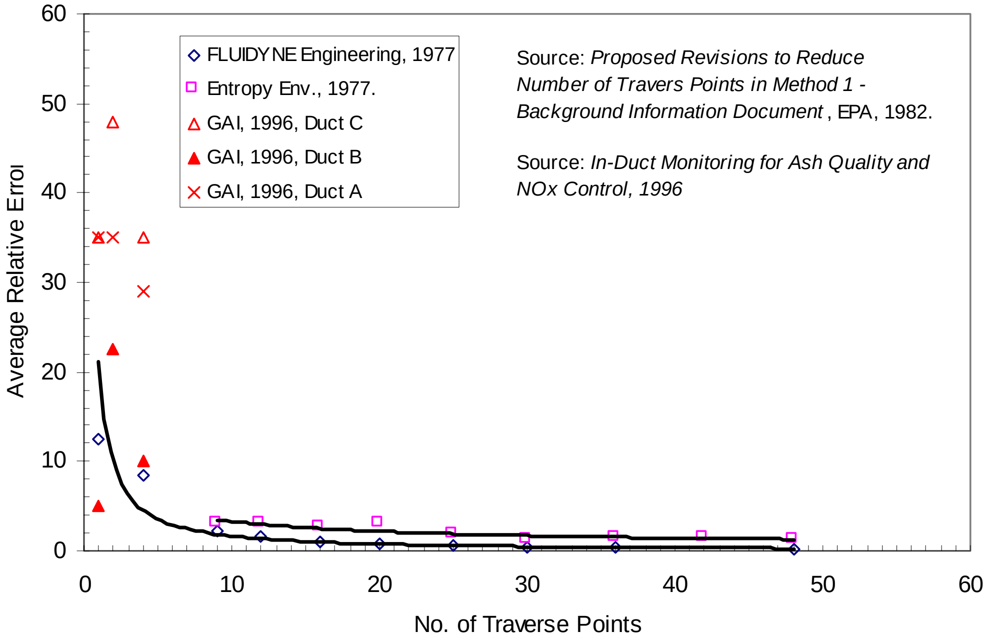


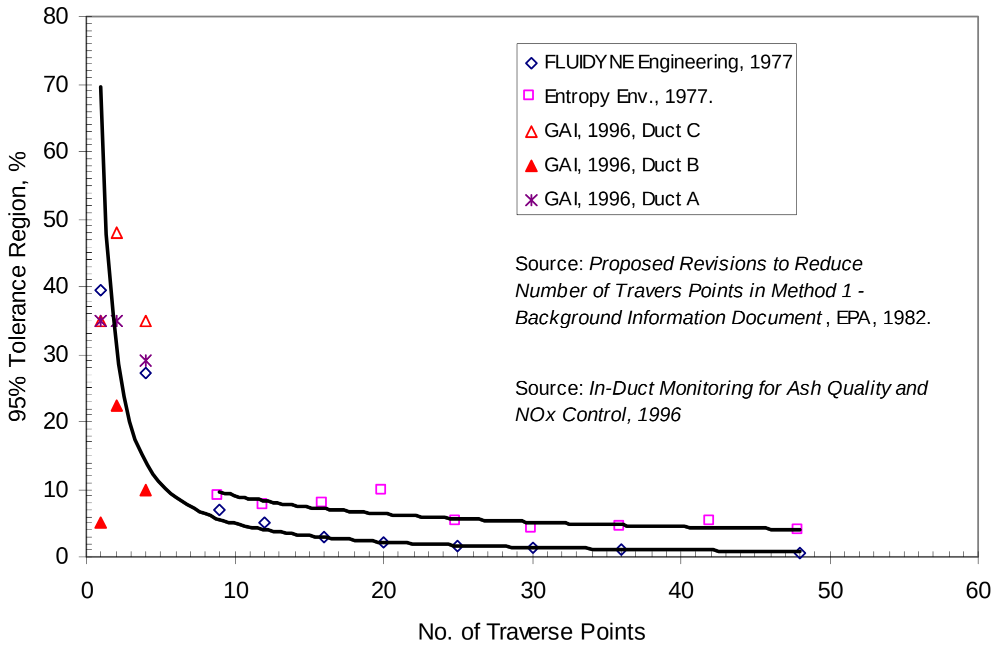
Figure 2-4
Velocity Mapping for a 500 MW Wall-Fired Unit - Regions of the Duct With Calculated Velocity ±5% of the Duct Mean Velocity.



Source: *Proposed Revisions to Reduce Number of Travers Points in Method 1 - Background Information Document*, EPA, 1982.

Source: *In-Duct Monitoring for Ash Quality and NOx Control, 1996*

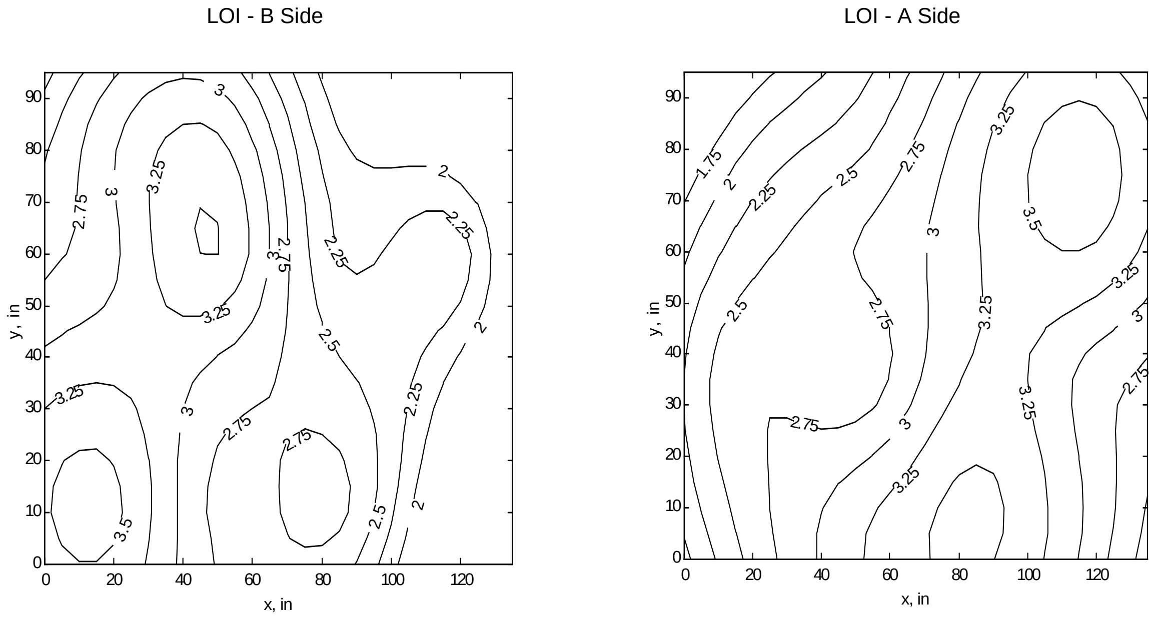
Figure 2-5
Average Relative Errors in Mass Rate as a Function of Number of Probes



Source: *Proposed Revisions to Reduce Number of Travers Points in Method 1 - Background Information Document*, EPA, 1982.

Source: *In-Duct Monitoring for Ash Quality and NOx Control, 1996*

Figure 2-6
Confidence Interval in Mass Rate as a Function of Number of Probes



Source: C. Tisch, et.al, *Optimize p-c combustion to reduce carbon in flyash*, Power, December 1990, pg. 31.

Figure 2-7
LOI Mapping for an 85 MW Tangential-Fired Unit

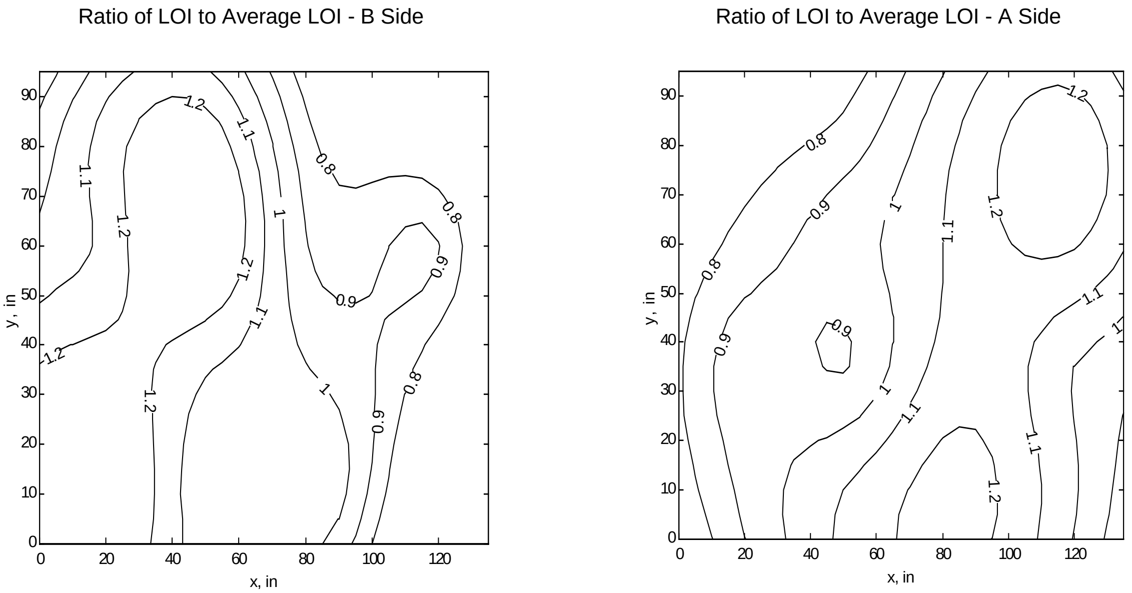


Figure 2-8
LOI Mapping for an 85 MW Tangential-Fired Unit – Ratio of LOI to Average LOI.

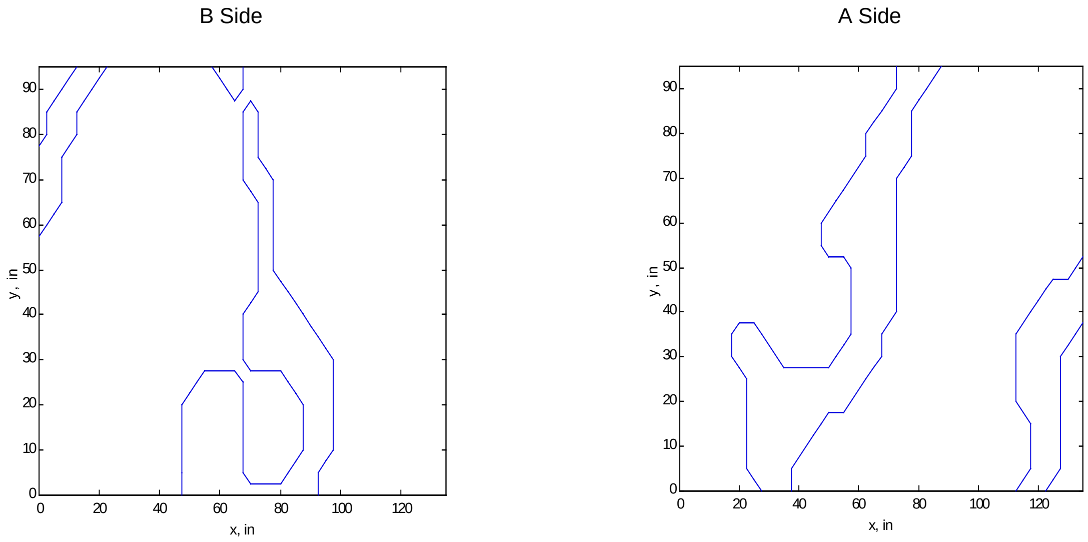


Figure 2-9
LOI Mapping for an 85 MW Tangential-Fired Unit - Regions of the Duct With Calculated LOI Within ±5% of the Duct Mean LOI.

Isokinetic vs. High Volume

The accuracy of an extractive CIAM is dependent on its ability to obtain a representative sample of fly ash. The ability to collect a representative sample in part depends on the rate at which the flue gas/fly ash mixture is extracted from the flue gas stream. When the extraction velocity in the probe is the same as that of the local flue gas stream, the sample is said to be extracted isokinetically. Super-isokinetic or high volume sampling occurs when the extraction velocity is greater than the flue gas stream in the vicinity of the extraction probe. High volume sampling is sometimes preferred because it can be less costly and time consuming than isokinetic sampling.

In general, UBC level is fly ash particle size dependent with the larger ash particles having a relatively larger UBC level than the smaller ash particles [EPRI, 1995]. An example of this is shown in Figure 2-10, in which the larger particles (> 75 µm in diameter) have on average LOI of about three times greater than the smaller particles [SCS, 1997]. These results are from a 500 MW wall-fired unit with LNBs burning eastern bituminous coal with a 10% ash content. The trend is similar to that reported by EPRI [EPRI, 1995]. When the flue gas is extracted isokinetically, the size distribution of the collected ash sample accurately portrays the free ash stream. The fly ash distribution from pulverized-coal boilers is shown in Figure 2-11 [Reinauer, 1967][EPRI, 1987]. When the sample is collected super-isokinetically, the collected sample can be skewed to either the larger or smaller particles, depending on the effective density of the ash and carbon particles. Tests conducted by SCS on a wall-fired unit with LNBs burning eastern bituminous coal with 10% ash, indicate that the larger particle fraction is collected preferentially by high volume sampling, however, the skew depends on the combustion system, coal particle size distribution, and other coal characteristics. For a series of tests conducted by SCS, an average, positive bias of near 1 percent was found when using the high volume method (Figure 2-12) [SCS, 1997] [SCS, 1993].

Although more representative ash samples can be obtained using isokinetic sampling, there are drawbacks with the method. Extraction probes for CIAMs that employ isokinetic sampling are more complex than those CIAMs that do not since in addition to the flue gas/fly ash extraction nozzle, accommodations must be made to:

- Measure the gas stream velocity and temperature on a continuous basis.
- Change the extraction gas velocity to match the local flue gas stream velocity.

This increased complexity adds to the cost of the instrument and tends to decrease the instrument reliability. Also, if non-isokinetic, high volume probes are utilized, more probes can be typically installed at a reasonable cost, thereby, potentially reducing spatial stratification sampling errors.

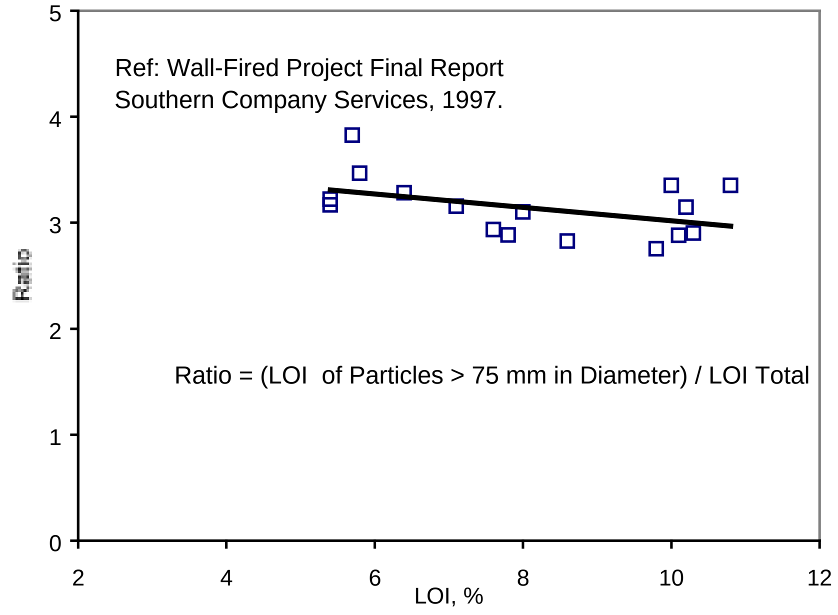


Figure 2-10
Ratio of LOI of Particles > 75 μm in Diameter to Average LOI.

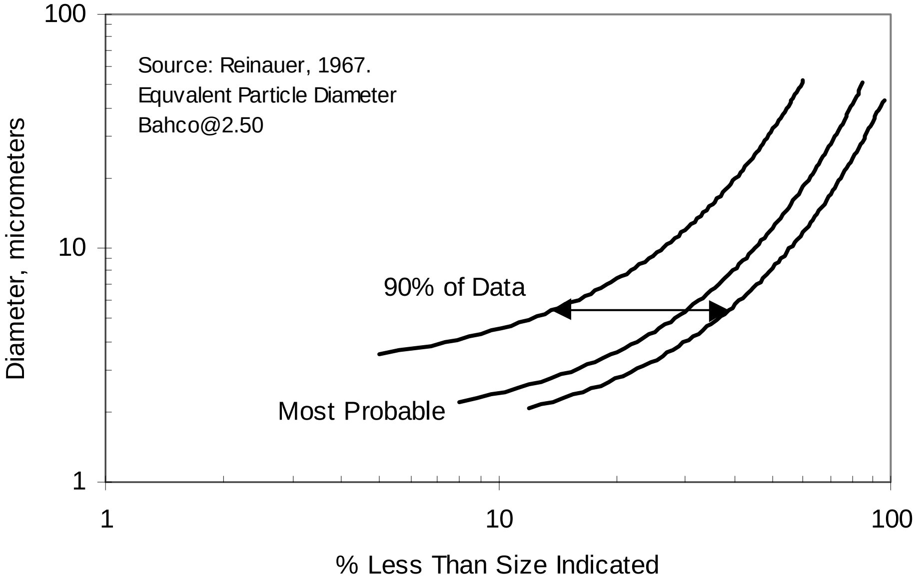
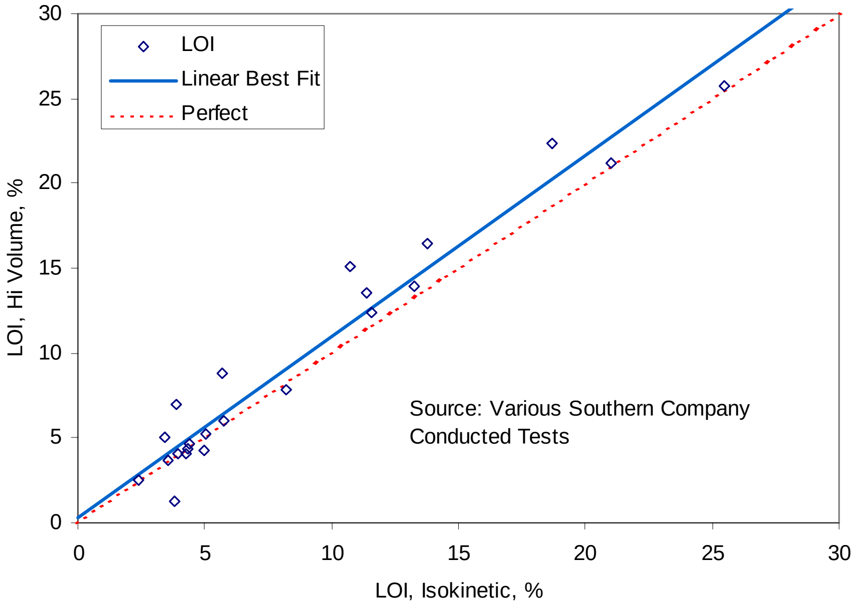


Figure 2-11
Fly Ash Particle Size Distribution in Pulverized Coal-Fired Boilers



Source: Various Southern Company Conducted Tests

Figure 2-12
LOI Comparison of Ash Sample Collected by High Volume and Isokinetic Methods

Technology Vendors

Over the past few years, several technologies for the on-line determination and monitoring of the unburned carbon content of ash samples have been developed and marketed (Table 2-2). Infrared, capacitance and microwave-based systems are some of the technologies that have been developed to aid in the on-line monitoring of unburned carbon content in ash.

Table 2-2
On-Line Carbon-in-Ash Vendors

Instrument	Type	Operating Principle	Status	Price Range	Vendor
AFR	NE	FTIR (Fourier Transform Infrared)	D	---	Advanced Fuel Research P. O. Box 380379 East Hartford, CN 06138 (860) 528-9806 phone (860) 528-0648 fax
CAM	EI	Microwave	C	$35k - $75k	CAMRAC Company, Inc. 570 Beatty Road Monroeville, PA 15146 (412) 856-3200 phone (412) 856-4970 fax
CEM	EI	Burn sample, measure CO_2	C	$85k	Rupprecht & Patashnick 25 Corporate Circle Albany, New York 12203 (518) 452-0065 phone (518) 452-0067 fax
CIFA	EI	Microwave	C	$50k	Scan Technologies 2915 Courtyards Drive, Suite B Norcross, GA 30071 (770) 447-8008 phone (770) 447-8038 fax
Cigma	EI	Burn ash sample, measure CO_2	NLA	---	Bristol Babcock
Concarb 2000	NE	Infrared	C	$50k	Penn Worldwide Inc. 785 William Pitt Way Pittsburgh, PA 15238 (412) 826-3903 phone (412) 826-3215 fax
Desktop 2000	M	Infrared	C	$17k	Penn Worldwide Inc. 785 William Pitt Way Pittsburgh, PA 15238 (412) 826-3903 phone (412) 826-3215 fax

Status – C = Commercial, D = Development, NLA = No longer available.
Type – EI = Extractive, isokinetic, EH – Extractive, high volume, NE – Non-extractive, M - Manual

Table 2-2
On-Line Carbon-in-Ash Vendors (continued)

Instrument	Type	Operating Principle	Status	Price Range	Vendor
FOCUS	NE	Infrared emissions	C	\$40k - \$80k	Applied Synergistics, Inc. 19206 Forest Road Lynchburg, VA 24502 (804) 385-6102 phone (804) 385-0714 fax
Hot Foil	M	Burn sample, determine weight loss	C	\$5k	Fossil Energy Research Corp. 23342-C South Pointe Laguna Hills, CA 92653 714-859-4466 phone 714-859-7916 fax
MPV-1	NE	*Proprietary*	C	\$25k - \$50k	MK Engineering, Inc. 28 Alcott Way North Andover, MA 01845 (508) 686-4192 phone (508) 661-9149 fax
RCA	EI	Infrared reflectance	C	Single point \$43k – \$45k Dual point \$73k – \$75k	M&W Ash Systems, Inc. 2160 Kingston Court, Suite H Marietta, Georgia 30067 (770) 984-2770 phone (770) 984-9901 fax
SEKAM	EH	Capacitance	C	\$45k - \$50k	Clyde Pneumatic Conveying Shaw Lane Industrial Estate Doncaster South Yorkshire DN24SE UK +44 1302 321313 phone +44 1302 369055 fax
Table-Top	M	Microwave	C	\$18k	CAMRAC Company, Inc. 570 Beatty Road Monroeville, PA 15146 (412) 856-3200 phone (412) 856-4970 fax

Status – C = Commercial, D = Development, NLA = No longer available.
Type – EI = Extractive, isokinetic, EH – Extractive, high volume, NE – Non-extractive, M - Manual

3

TEST PROGRAM DESCRIPTION

In view of the importance of fly ash characteristics of ash sales and combustion performance and the potential use of CIAMs in on-line optimization strategies, the Electric Power Research Institute, Southern Company, and U.S. Department of Energy undertook demonstrations of several CIAM technologies at Georgia Power Company's Plant Hammond Unit 4 and Alabama Power Company's Gaston Unit 4. In general, goals of the test program were as follows:

- Compare accuracy of CIAM readings versus laboratory determinations of ash samples.
- Determine the response time of analyzers to changes in boiler conditions.
- Compare isokinetic duct conditions to instrument readings and ESP hopper samples.
- Estimate availability and durability of instruments using current information on equipment problems (type and duration).
- Judge potential for a CIAM to be incorporated into on-line boiler optimization systems.

The testing was conducted from December 1995 through August 1996. A description of the test activities is shown in Box 3-1. Composite duct samples were collected on the "A" and "B" sides during each test. These samples were collected at three different loads and oxygen levels. A duct traverse was conducted at low, normal, and high oxygen levels while the unit was running at high, medium, and low loads (Box 3-2). In addition to the composite duct samples collected during the duct traverse, ESP hopper samples were collected from the front row of hoppers on "A" and "B" sides during each test. The CIAM instrument readings were also recorded by the DCS or DAS.

Instrument Accuracy

Instrument accuracy was determined in two ways. First, composite isokinetic duct samples for each test were compared to average CIAM readings taken during the same testing period. While this method does represent the overall accuracy of the instrument as installed, it also reflects duct stratification errors. That is, the instrument readings were based on probe locations in the duct that may not be representative of the average value represented by the duct composite sample. These stratification errors can vary greatly from test to test or site to site and therefore makes extrapolation of results to other sites or different operating conditions difficult.

The second method involved placing ash samples directly into the CIAM's evaluation cell for analysis and then comparing the instrument and laboratory determined values. This method afforded the opportunity to test not only the ash where the instrument was installed, but other plants as well. The latter method was only feasible on the extractive systems. An advantage of this procedure is that it removes concerns about collecting representative samples to compare with duct composites. In addition, it allowed using other ash sources which would provide a larger range of LOI values over which to evaluate CIAM accuracy. This type of testing is not a normal operating practice but one specifically conducted to test the accuracy of the instrument with carbon content and coal source variation.

Box 3-1
Description of Planned Test Activities

Isokinetic Fly Ash Sampling - Isokinetic fly ash sampling will be conducted at the precipitator inlet. Two samples will be collected per test, one representing the "A" side of the furnace and another representing the "B" side of the furnace. Test contractor will have primary responsibility for the ash collection and will be assisted by SCS personnel. The collected samples will be shipped back to SCS for subsequent loss-on-ignition and carbon analysis.

Precipitator Hopper Sampling - One fly ash sample will be collected from each of the leading precipitator hoppers per test. Sampling from the hoppers will start 15 minutes after start of current test. The samples from each hopper will be individually labeled and bagged for subsequent analysis by SCS. SCS personnel will have primary responsibility for the collection of these samples.

Coal Samples - A composite coal sample will be collected at the feeder inlets at the start and end of the test day. The two composite samples will be subsequently analyzed by SCS.

Automatic Data Collection - The data acquisition system and/or digital control system will be used to record process parameters during the testing. The following parameters are of particular importance during this test sequence: unit load, NOx, CO, CIAM readings, LOI, excess oxygen, overfire air flow rates, and mill primary air and fuel flows.

Although placing samples into the CIAMs did provide additional performance information, there were some difficulties with this technique on some instruments. First, generally, the CIAMs manufacturers did not provide the capability for the easy insertion of fly ash in the analysis cell. This posed two problems: (1) significantly extending the time to perform the insertion /analyze/removal cycle and (2) increasing the risk of removing a non-representative ash sample from the analysis cell (on one instrument only). Another complication in this method is that the CIAM's analysis may be influenced by moisture in the ash. Because fly ash is hygroscopic, the moisture content can change between the ash collection time, insertion into the CIAM, and laboratory analysis.

Box 2-2
Test Plans (Hammond)

CIAM Test Plan

Unit Load Requirements

Date	Requested Load	Time (CST)
Thursday, February 8	500 MW (full-load)	8:00 AM - 3:00 PM*
Thursday, February 8	400 MW	4:00 PM - 10:00 PM
Friday, February 9	300 MW	10:00 AM - 4:00 PM

*First test to begin at approximately 9:00 am

Test Matrix

Test Number	Date	Load (MW)	Excess O2	Overfire Air	Description	Tests Conducted
152-1	Feb 8	520	Low	Nominal	High Load LOI	GAS, ISO, HOPPER, COAL
152-2	Feb 8	520	Nominal	Nominal	High Load LOI	GAS, ISO, HOPPER, COAL
152-3	Feb 8	520	High	Nominal	High Load LOI	GAS, ISO, HOPPER, COAL
152-4	Feb 8	400	Low	Nominal	Mid Load LOI	GAS, ISO, HOPPER, COAL
152-5	Feb 8	400	Nominal	Nominal	Mid Load LOI	GAS, ISO, HOPPER, COAL
152-6	Feb 8	400	High	Nominal	Mid Load LOI	GAS, ISO, HOPPER, COAL
153-1	Feb 9	300	Low	Nominal	Low Load LOI	GAS, ISO, HOPPER, COAL
153-2	Feb 9	300	Nominal	Nominal	Low Load LOI	GAS, ISO, HOPPER, COAL
153-3	Feb 9	300	High	Nominal	Low Load LOI	GAS, ISO, HOPPER, COAL

GAS - Basic flue gas sampling
ISO - Isokinetic fly ash sampling at ESP inlet
HOPPER - Fly ash hopper samples
COAL - Coal samples will be taken at the beginning and end of the test day

Instrument Response Time

The time required for each unit to recognize a change in furnace operating condition was also considered in the evaluation. The test series consisted of sampling at three loads and three excess oxygen levels at each load. To monitor the response of each instrument, the load and oxygen levels were plotted along with the UBC (or LOI) readings for each unit over a period of time. For one extractive instrument (SEKAM), the total sample collection / analysis time was sometimes greater than the individual test duration (particularly at low loads) and therefore, the instrument reading did not reach a steady state value.

Estimation of Duct LOI Using Hopper Samples

As the isokinetic, multi-point duct traverses were performed, samples were also being removed from the front row of hoppers on both "A" and "B" sides. These samples were compared with the duct composite samples taken for the corresponding test. This comparison was made to investigate the possibility of using ESP hopper samples to predict LOI. The hoppers were dumped prior to the start of each test run and an ash sample collected from the hopper at least 15 minutes after the start of the test. This procedure minimized the risk of obtaining a hopper ash sample not being representative of the current operating conditions.

Equipment Problems

In addition to performance testing, a log was kept to reflect the availability of each unit and the problems encountered during operation.

Test Sites

Testing was conducted at Georgia Power Company's Hammond Unit 4 and Alabama Power Company's Gaston Unit 4 (Table 3-1). A brief description of the units is provided below.

Table 3-1
Host Sites and CIAMs Tested

Site	CIAMs Tested
Hammond 4	CAM FOCUS SEKAM
Gaston 4	CAM RCA

Hammond Unit 4

Georgia Power Company's 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. Six B&W MPS 75 mills provide pulverized eastern bituminous coal (12,900 Btu/lb, 33% VM, 53% FC, 72% C, 1.7% S, 1.4% N, 10% ash) to 24 Foster Wheeler Control Flow/ Split Flame low NOx burners. The burners are arranged in a matrix of 12 burners (4W x 3H) on opposing walls with each mill supplying coal to four burners per elevation. In addition to the low NOx burners, the furnace is equipped with a Foster Wheeler advanced overfire air system. The Unit 4 boiler was designed for pressurized-furnace operation but was converted to balanced draft operation in 1977. The unit is equipped with a coldside ESP and utilizes two regenerative secondary air heaters and two regenerative primary air heaters. A Foxboro I/A digital control system is used for combustion control. Plant Hammond is located near Rome, Georgia.

Gaston Unit 4

Alabama Power's Gaston Unit 4 is a 270 MW pulverized-coal unit. The Babcock and Wilcox (B&W) opposed-wall-fired boiler is arranged with nine burners (3W x 3H) on two opposing walls such that no burner has another burner directly across from it. Combustion air is supplied to the burners via common wind boxes on each side of the boiler. The unit is equipped with B&W XCL low NO_x burners and six B&W EL-76 ball and race mills. Fuel is delivered to the mills by two-speed table feeders. The unit has two forced-draft fans, six primary air fans, and two flue gas recirculation fans. Combustion air is heated with Ljungstrom air heaters. The boiler control system for Gaston Unit 4 is a Leeds and Northrup MAX 1000 distributed digital control system. Plant Gaston is located near Wilsonville, Alabama.

4

SUMMARY OF OBSERVATIONS

On-line carbon-in-ash monitors have been available commercially for over ten years. However, to date they have not been deployed widely in the U.S. despite potential uses for combustion optimization and as an aid in fly ash marketing. Based on the lack of publicly available performance and operation data available for the current commercial offerings, Southern Company initiated a demonstration of several commercial technologies on Southern Company coal-fired units. Detailed instrument descriptions and test results can be found in the appendices. A summary of the observations from the demonstrations is as follows:

- CIAMs are, in general, useful for determining LOI trends.
- CIAMs are not particularly useful for determining absolute LOI levels.
- CIAMs are useful for on-line combustion optimization if consideration is given in the optimization methodology that the results obtained from the instrument are useful primarily for determining trends.
- Generally, the instruments are less reliable, less robust to changes in boiler operating conditions, and require more service than typical instrumentation found in power plants. If CIAMs are to be used successfully, a commitment must be made by plant staff to provide periodic maintenance to these instruments, possibly on a weekly or monthly basis.
- The relatively high capital and maintenance costs of the current commercial offerings (again compared to other plant instrumentation) are a major hindrance to further deployment, especially in view of (1) reliability and accuracy concerns and (2) the perception that these instruments are more of a luxury than a necessity. These costs vary greatly from instrument to instrument.
- Follow-up vendor support is a concern. Many of these instruments are from relatively small companies or from companies who do not have service representatives domestically. Also, because in general the CIAMs are produced in extremely low quantities, there is a tendency for the vendors not to keep spare parts

in inventory. Another factor is that for a number of vendors, the CIAMs continue to evolve, leading to one-of-kind installations.

Many of the above support problems may be resolved once there is a large user base in the U.S. However, at this time, no manufacturer has an installed base of greater than 10 instruments in the U.S. A positive factor is that the vendors continue to improve their products while other technologies are planned for commercialization in the near future.

Although the demonstration program was not intended as a competition between vendors, a byproduct of the side-by-side testing is that some comparisons of this nature can be made. Based on the testing at Gaston and Hammond, no CIAM was superior to the other monitors in all performance categories. The relative merits of each analyzer are shown in Tables 4-1 and 4-2. This performance is based on testing at these two sites only and may not be indicative of the performance of these CIAMs at other sites. Further information on the performance of these instruments can be found in the appendices. Also, some of the CIAMs have been tested at other sites and some of these results have been published (see bibliography).

Table 4-1
Relative Performance

Instrument	Operating Principal	Accuracy	Response Time	Reliability	Coal Flexibility
CAM	Extractive / Microwave	+	+	+/-	+
FOCUS	Non-extractive / Infrared Camera	-	+	+	?
RCA	Extractive / Infrared Reflection	N	+	+	-
SEKAM	Extractive / Capacitance	N	-	+	N

+	Advantage
-	Disadvantage
N	Neutral results
?	Unknown / not evaluated

Table 4-2
Relative Availability

	SEKAM	CAM	FOCUS	RCA
Installed:				
Hammond	Nov. 1994	Mar. 1995	July 1995	---
Gaston	---	July 1996	---	Feb. 1996
Availability:				
Hammond	High	Moderate - Low	High	---
Gaston	---	High	---	High

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CAM

The CAM (Carbon-in-Ash-Monitor) was developed by GAI Consultants during the 1980's for the CAMRAC Company. EPRI and several utilities provided financial support for development. The system offers automatic monitoring of unburned carbon in combustion products. As of June 1996, five CAM instruments had been installed at various locations. The system has been installed on Alabama Power Company's Plant Gaston Unit 4 and Georgia Power Company's Plant Hammond Unit 4. Other locations include Pennsylvania Electric's Conemaugh Station, Allegheny Power's Harrison Plant, Philadelphia Electric's Eddystone Plant and Duquesne's Cheswick site.

The CAM's operating principle is based on the microwave absorption properties of carbon particles. A sample of fly ash (~5 grams) is automatically extracted from the duct isokinetically and deposited in a collection cell (Figure 1). Microwaves at the frequency of 2450 MHz and a power level of approximately 150 mw are passed through the collection cell. The microwave power into the collection cell minus the transmitted and reflected power is equivalent to the power absorbed by the ash sample. Using the absorbed power, relative absorption of the microwaves between carbon and carbon-free ash is used to estimate the carbon content of the sample. An internal calibration curve is used to convert this absorption to percent carbon and display LOI units. The system transmits the results of the sample analysis to the plant control room for possible display and combustion performance optimization. The interrogated sample is then returned to the combustion duct.

CAMRAC recommends that the fly ash extraction location be between the economizer and the air heater; however, locations downstream of the air heater can be accommodated. The system is designed to operate up to ten adaptive samplers and has several measurement options. For single point sampling, the collection cell is purged and a new ash sample is collected for analysis every five to ten minutes, dependent on local ash loading. In a multiple probe installation, the sampling and analysis time is approximately the sample time for a single probe multiplied by the number of probes. According to the manufacturer, the instrument calibration is to a large degree independent of the coal source. Therefore, in theory, the instrument could be calibrated for one ash type, which would be valid for all coals utilized in the boiler. The CAM electronics and measurement cell are shown in Figures 2 and 3 and the sampling probe is shown in Figure 4.

Table 1 provides various aspects of the system including size, accuracy and cost. These specifications were taken from literature provided by the vendor.

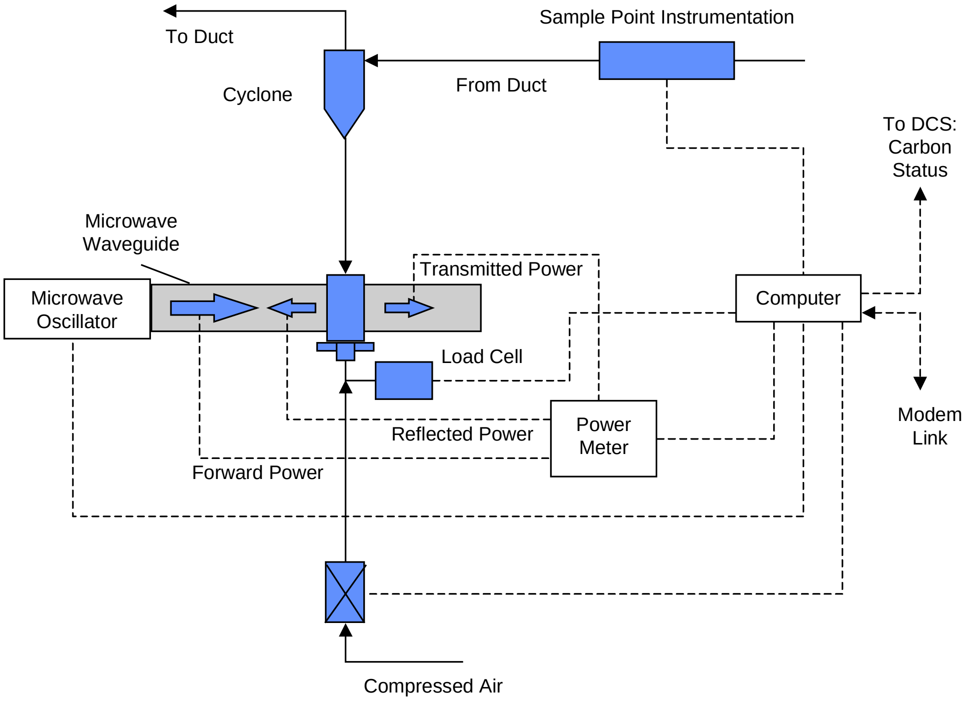

Figure 1
CAM General Arrangement (Single Point Installation)

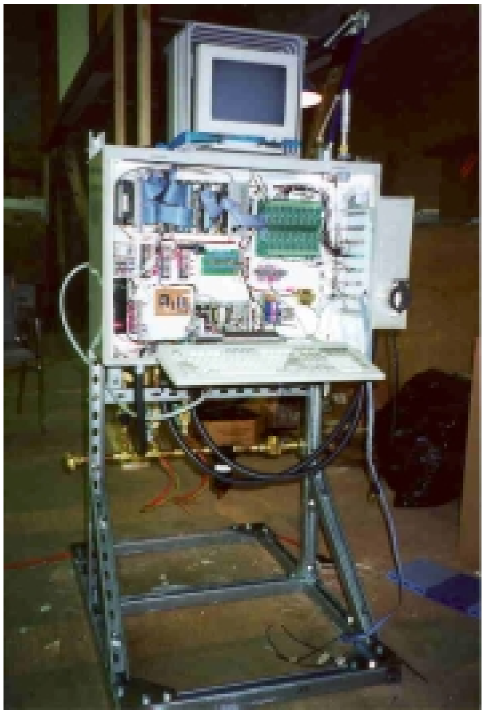

Figure 2
CAM Carbon-in-Ash Monitor (Interior View)

Figure 3
CAM Carbon-in-Ash Monitor (Rear View)

Figure 4
CAM Sample Probes

Table 1-1
CAM General Information

CAM Carbon-in-Ash-Monitor	
Operating Principle	Microwave absorption
Instrument Size (W x D x H)	3 ft x 4 ft x 6 ft
Instrument Weight	300 lb
Power Requirements	110 VAC / 10 amps
Instrument Air	100 psi / 10 scfm
Plant Air	not required
Ambient	10°F to 140°F, 0% to 100% RH
Mobility	instrumentation: medium sampling device: medium
Sample Size	4-6 grams
Quoted Range	0 –100% carbon content of the ash
Quoted Accuracy	± 0.5% (absolute) below 5% carbon ± 10% (relative) above 5% carbon
Analysis Display	actual % carbon of collected sample
Response Time	~ 5 minutes
Normal Maintenance	• Calibrate pressure cells and load cells every 6 months • Check against lab analysis • Replace air filters (frequency dependent on air quality)
Cost	$35,000 -$75,000 depending on options, sample points
Contact	Doug Trerice or Anthony DiGioia CAMRAC Company, Inc. 570 Beatty Road Monroeville, Pennsylvania 15146 (412) 856-3200 phone (412) 856-4970 fax

Installation

The purchase order for the CAM system was placed with CAMRAC during September 1994. The system was delivered to Georgia Power's Plant Hammond during January 1995. CAMRAC representatives initially commissioned the CAM on Unit 4 during March 1995; however, during the time at Hammond, the instrument had relatively low availability and required frequent service calls by CAMRAC. A design goal was to make the instrument installation at Hammond somewhat portable with the ability to perform traverses of the flue gas stream at the economizer outlet. The single point instrument was installed at the air heater outlet just prior to the precipitators (Figure 5). Although CAMRAC would have preferred a sampling location prior to the air heaters, this was not possible because of physical constraints. Also, locating the instrument before the air heaters would have severely hampered gas path traverses.

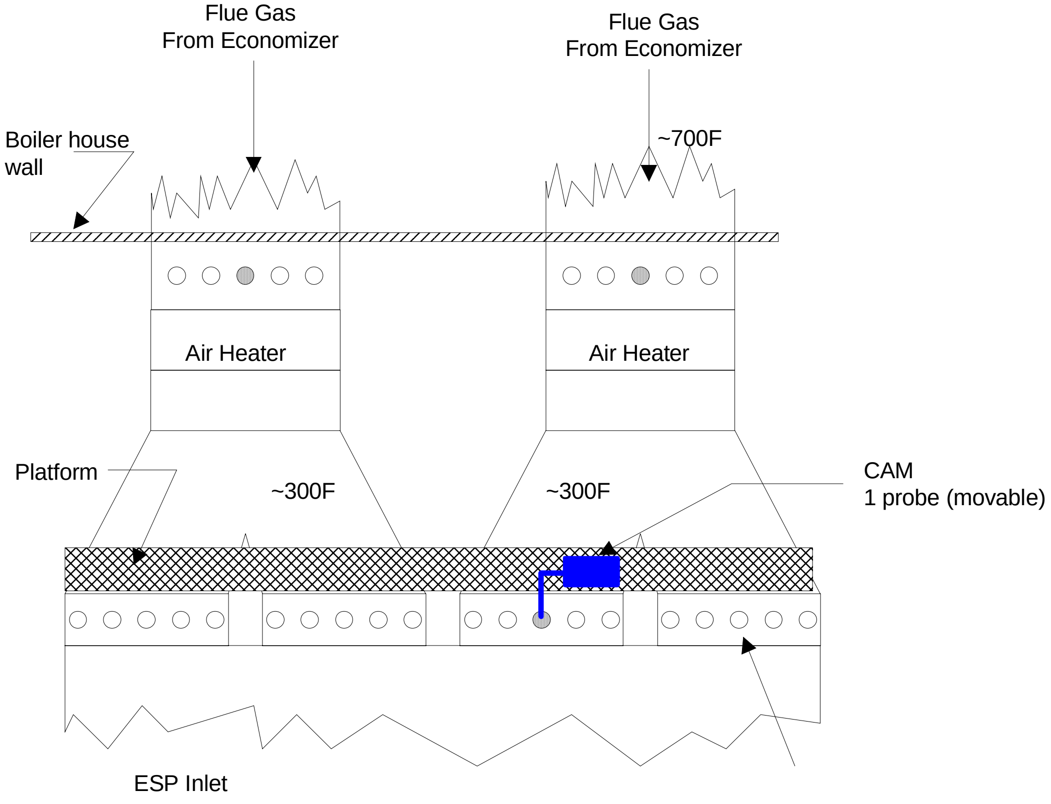

Figure 5
Installation of CAM at Hammond 4

In general, the installation of the instrument was very simple with the following being the major activities:

- Placement of the CAM on the platform adjacent to the sampling locations. Because the CAM system weighs less than 300 lb and has a small footprint (approximately 12 ft^2), placement of the instrument was not at all difficult.
- Supply temporary plant air and power to the instrument. Existing local outlets for air and power were utilized.
- Addition of input points to the DCS. The CAM supplies a single output to the DCS representing LOI. The signal wires between the CAM and the DCS are terminated at the remote termination unit of the DCS located near the AOFA level of the furnace.

Existing sample ports, for both collection and return of the ash to the flue gas stream, were utilized, so installation of ports was not necessary.

Although it was hoped that the CAM unit could be used to perform duct traverses, as a result of several design features of the particular unit installed at Hammond, this goal was not achieved. The primary problems were associated with the use of rigid piping for the sample and return lines of the CAM. Based on some preliminary tests, it was estimated that it would take approximately 30 minutes per sample location in just moving the probe. This is significantly longer than required to perform manual isokinetic traverses. The rigid system was a compromise between reliability and traverse flexibility. As opposed to a flexible system, a rigid system is more readily heat traced and ash erosion resistant. Also, a consideration in the choice of a rigid system was that the sample probe was installed in a duct where the flue gas temperature was near the condensation temperature.

During July 1996 after completion of the test program at Hammond 4, the CAM unit was moved to Alabama Power's Gaston Unit 4 for further testing. At Gaston 4, the CAM was installed on the hot side of the air heater on a vertical duct (Figure 6). The installation scope was much the same as at Hammond with temporary plant air, power wiring, and instrumentation wiring provided. Existing sampling ports were utilized for the Gaston installation. The unit was commissioned again by CAM representatives and was operational August 1996.

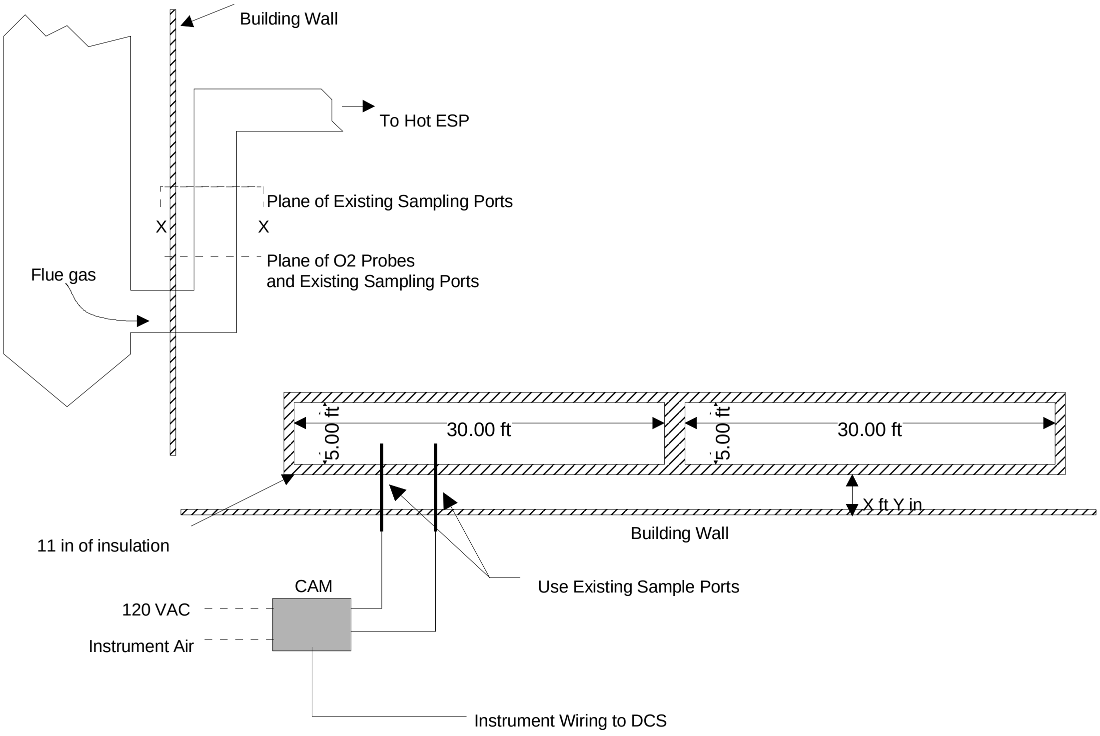

Figure 6
Installation of CAM at Gaston 4

Comparison of CAM to Manually Collected Samples

Testing of the CAM system was conducted at Plant Hammond and Plant Gaston. The first round of testing of this instrument was conducted July 20 and 21, 1995 at Hammond. 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 (300, 400, and 500 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 receives roughly 70% of the fly ash collected by the precipitator. Because the CAM set-up at Hammond provides a reading representing the "A" side only, it was compared to the samples collected from the "A" duct only.

A second round of testing of the instrument was conducted February 8 and 9, 1996 at Hammond. The scope of the testing was similar to that conducted during July 1995 with isokinetic and hopper samples being collected.

The third round of testing was conducted at Gaston on August 27 and 28, 1996. Seven tests were conducted representing three load levels (135, 200, and 270 MW). During each of the seven tests, composite duct samples were collected from the flue gas stream at the air heater inlet – one each from the "A" and "B" side of the precipitator. Hopper samples were not collected for the tests at Gaston. Because the CAM was sampling from the "A" duct, it was compared to the "A" side samples only.

A comparison of the CAM readings to that of the isokinetically collected samples from the July 1995 testing is shown in Figure 7. As shown, the CAM provided a relatively accurate prediction of these values. A comparison of the CAM readings to the hopper samples (side "A" only) is shown in Figure 8. Results from the second round of testing at Hammond are shown in Figures 9 and 10. As shown, although the variation of the error was similar to that seen in the July 1995 tests, a consistent positive bias (averaging approximately 3.5 percent) was observed. This bias was also evident in the hopper samples. The reason for the greater bias is unknown; however, potential factors include:

- Changes in coal characteristics. Although this could have been a factor, during the period the instrument was installed at Hammond, the unit has had a fairly consistent coal supply. Also, according to CAMRAC, the CAM calibration is not dependent on coal characteristics.

- Calibration shifts in the instrument. From the initial installation in first quarter 1995 to removal of the instrument in second quarter 1996, CAMRAC representatives performed numerous maintenance and warranty related service calls on the instrument, including part replacements and re-calibrations.

- The CAM collecting a non-representative sample. Prior to the installation of the CAM, no mapping of the flue gas stream was conducted to determine the most representative sample location. However, even if this mapping had been done and the sample probe placed at the most representative location, there is no assurance that this location would have not drifted significantly during the time the instrument was installed at the site.

The results from the testing at Gaston are shown in Figure 11. At this site, the CAM was not as consistent as a predictor of the isokinetically collected ash LOI as what had been observed at Hammond. As shown, scatter increased substantially over that observed at Hammond. Although it is not known with certainty, the increase in error may be due to CAM's collection of a non-representative ash sample.

Inherent Accuracy

Accuracy of the CAM instrument was further evaluated by placing ash samples directly into the microwave evaluation cell. An advantage of this procedure is the removal of concerns about collecting representative samples to compare with duct composites. In addition, it presented an opportunity to select ash sources that would intentionally provide a larger range of LOI values over which to evaluate accuracy. Although sampling is eliminated as a source of error, other possible differences in instrument and lab LOI include moisture that could have been absorbed by the ash samples from the atmosphere during storage prior to use with the instruments. With the CAM analyzer, it is expected that moisture would result in a higher reading in that water molecules also absorb microwave energy.

The results of this testing while the unit was still at Hammond are shown in Figure 12. For these ash samples, the CAM showed the same general trend as the lab analysis. However, as with the isokinetic comparison (Figure 9), there was a considerable bias in the readings. The testing was conducted during November and December 1995. These results strengthen the proposition that the calibration of the instrument shifted between July 1995 and November 1995.

Similar tests were conducted while the CAM was at Gaston (Figure 13). As shown, the bias observed at Hammond was no longer evident. Also, because the instrument performance was better for these tests than for the isokinetic testing at Gaston, it appears that the majority of the error shown in Figure 11 may be attributable to the CAM's collection of a non-representative sample.

Time Response

When carbon-in-ash monitors are used for control and optimization, timeliness of the response is an important consideration. Factors affecting time response include:

- Ash mass flux at the sample probe location(s). The ash loading is in turn dependent on the unit load and ash content of the coal. At Hammond and Gaston, the aggregate ash mass flux at full load at both locations was approximately 0.09 grams/sec-cm^2.

- Required sample size. The CAM requires approximately 5 grams of ash to perform the analysis.

- Analysis time. Once the sample is collected, the CAM requires less than one minute to perform the analysis.

The response for the CAM is shown in Figure 14. During the time period shown, both unit load and excess oxygen varied. As shown, the total response time of the CAM to these changes were approximately 15 minutes at the loads shown. For greater loads, the response time is reduced whereas for lower loads, the response time is increased.

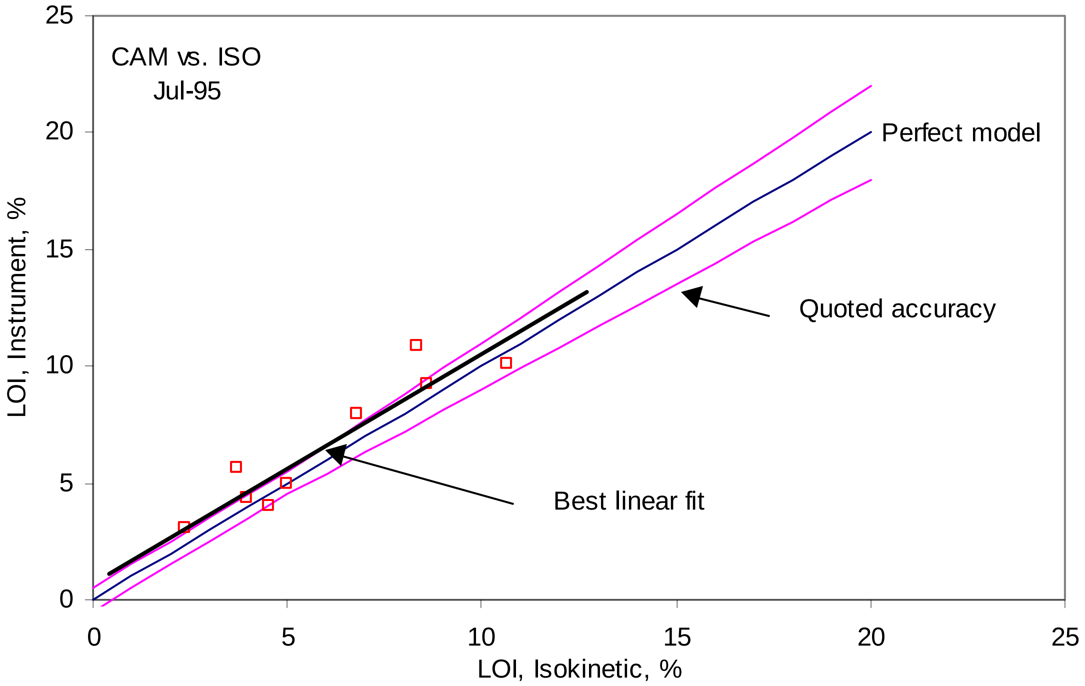

Figure 7
CAM vs. Isokinetic Samples – July 1995

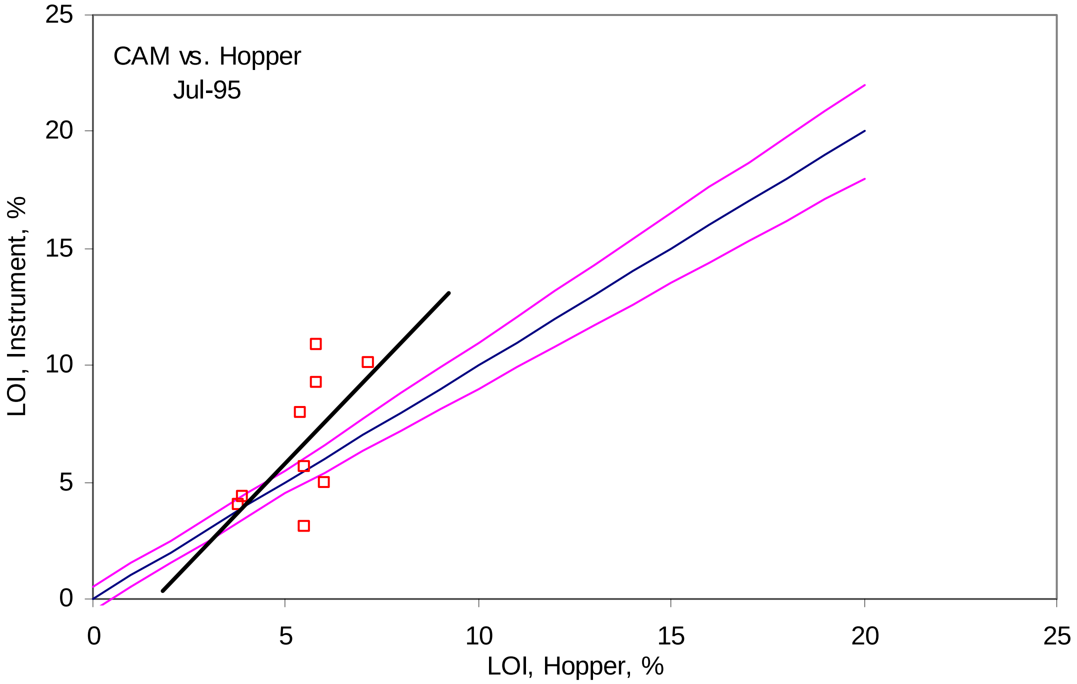

Figure 8
CAM vs. Hopper Samples – July 1995

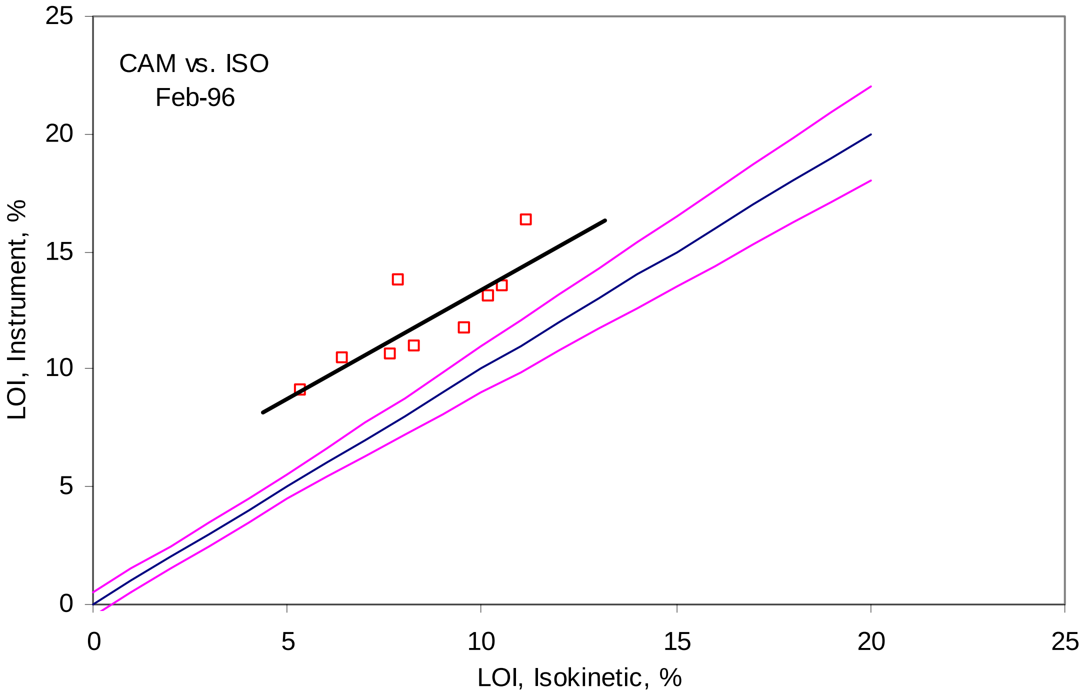

Figure 9
CAM vs. Isokinetic Samples – February 1996

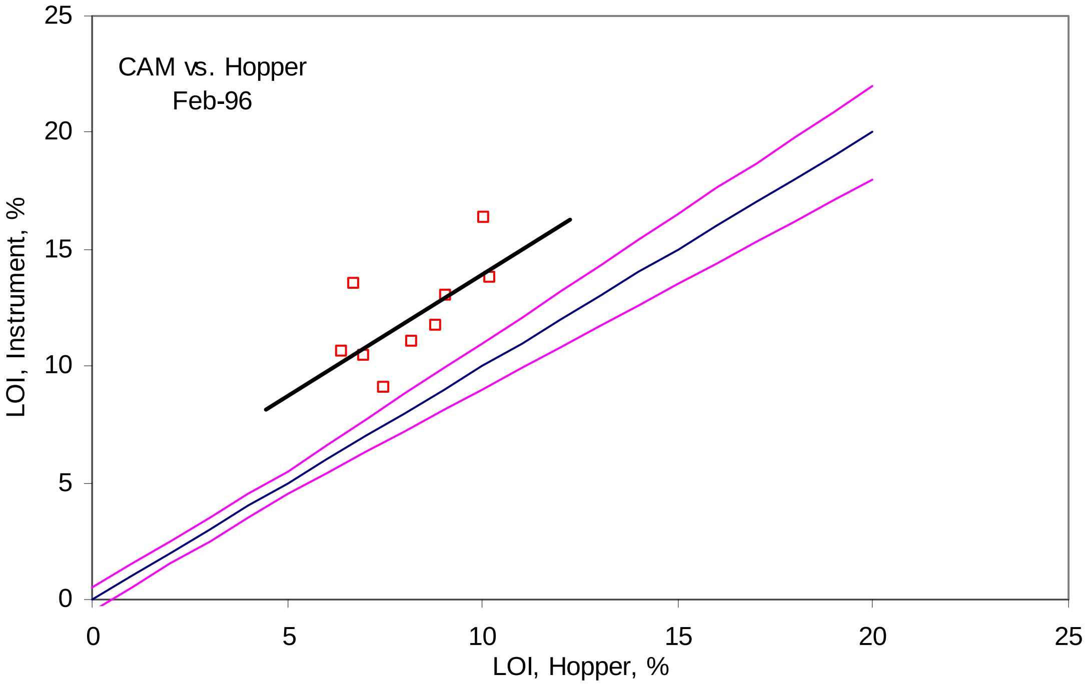

Figure 10
CAM vs. Hopper Samples – February 1996

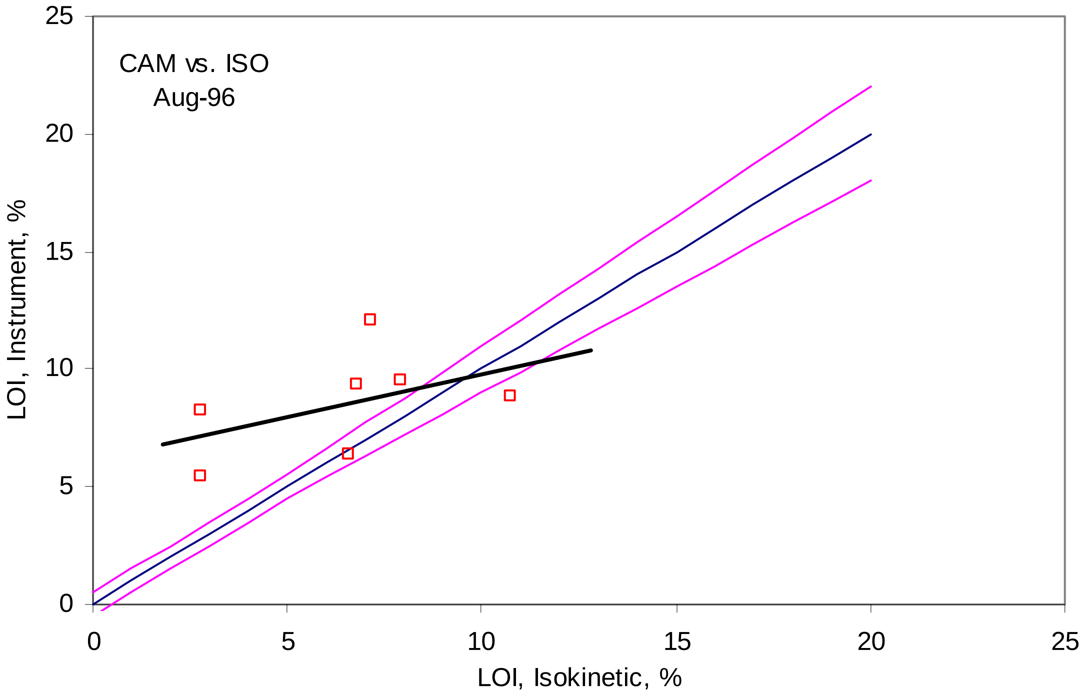

Figure 11
CAM vs. Isokinetic Samples – August 1996

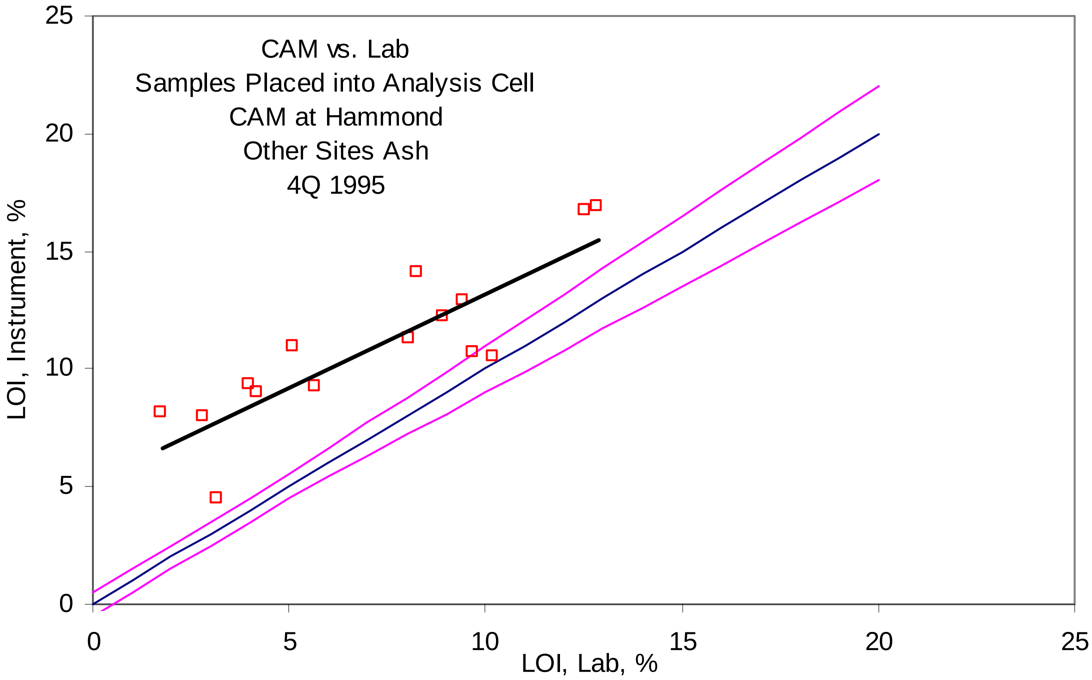

Figure 12
CAM Inherent Accuracy - Hammond

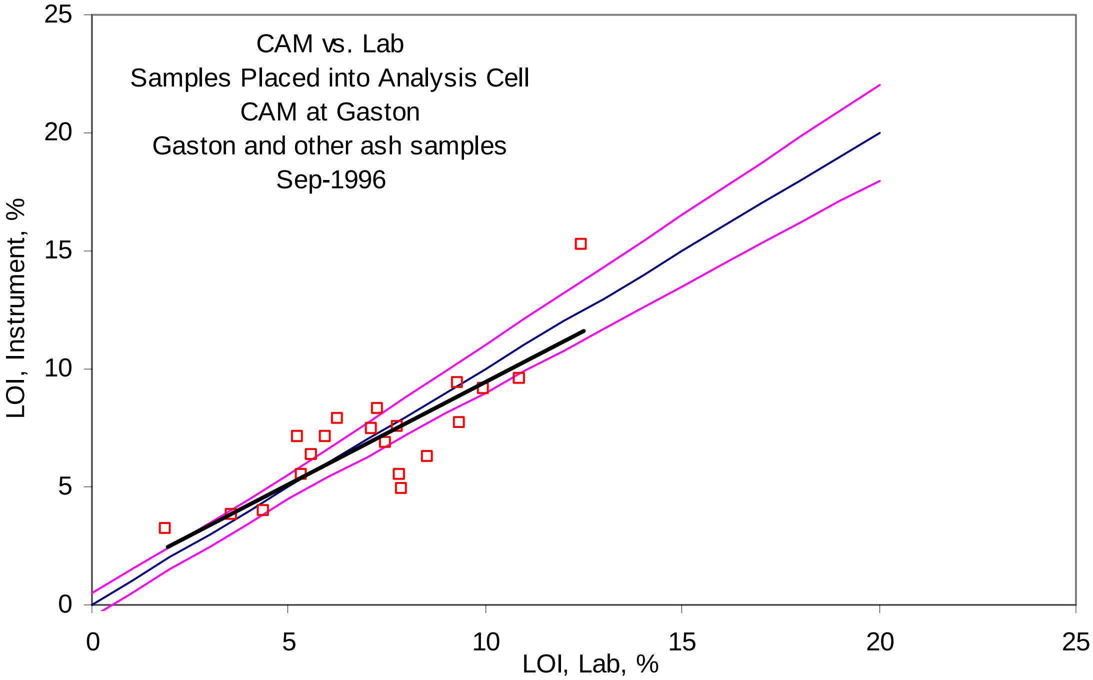

Figure 13
CAM Inherent Accuracy - Gaston

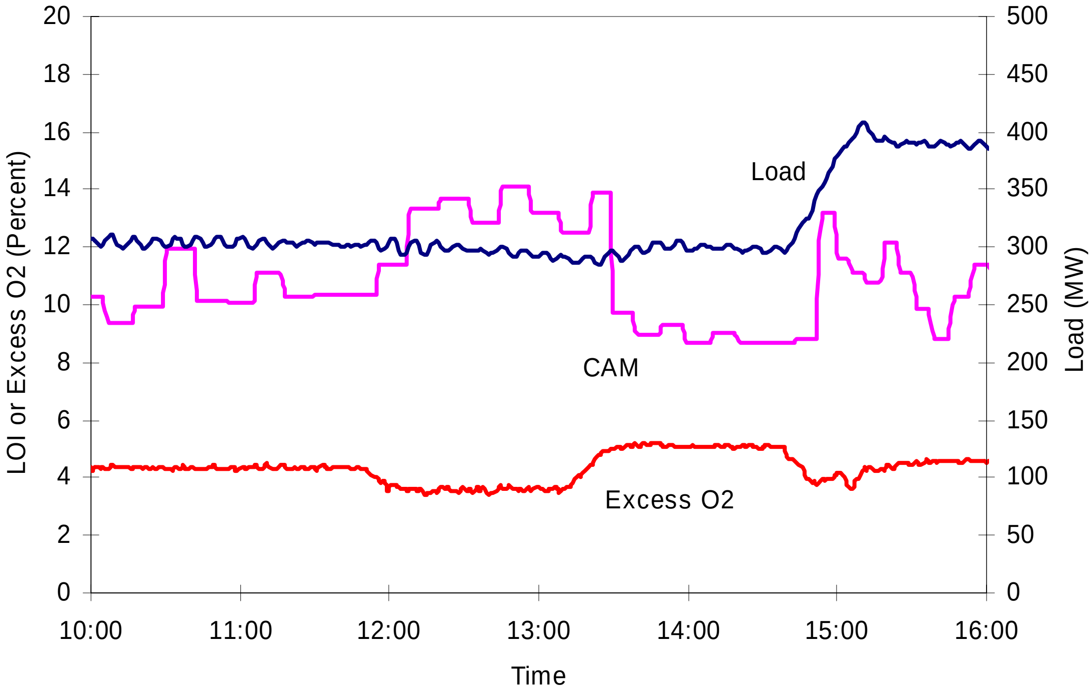

Figure 14
CAM Time Response

Reliability and Maintenance Aspects

The CAM LOI monitor was installed at Hammond during first quarter 1995 and removed from service during second quarter 1996. Over this period, the unit demonstrated low to moderate availability, with noticeable improvement in the latter portion of the operating period. Problems associated with this instrument included the following:

- Probe flanges too short; spacer inserted.
- Probes plugged; cleaned out probes.
- Unit shutoff due to a locked monitor; instrument restarted.
- Faulty heat tracing line; line replaced.
- Transmitter not working properly; transmitter replaced.
- Unit not responding during sample collection; weigh cell replaced.
- Moisture in plant air; additional filters installed.

CAMRAC attributed much of the maintenance problems with poor plant air quality and use of ignitor oil during unit startup.

During third quarter 1996, the CAM unit was placed in service at Gaston and continued to operate at that unit through second quarter 1997. In general, the CAM operated with fewer problems than observed at Hammond. The reason for the improvement may be related to:

- Improved plant air quality at Gaston.
- CAM was installed on the hot side of the air heater at Gaston whereas at Hammond it was installed downstream of the air heater.

FOCUS

Applied Synergistics' FOCUS (Furnace On-line CombUstion System) Unburned Carbon Module is a non-intrusive device that the vendor markets as a continuous real-time indicator of on-line unburned carbon levels in fly ash. The FOCUS operating principle is based on the premise that unburned carbon exiting the furnace will be hotter than the surrounding gases and carbon-free ash. Therefore, the carbon and carbon laden particles will emit higher levels of radiant energy in the near infrared wavelength range (~8000 Angstroms). Infrared video cameras installed along the wall of the furnace provide an image of these hotter particles as white spots. These images are then processed to determine the rate at which hot particle traverses the camera(s) field of view. One or more video cameras are installed on the furnace at a location where the flue gas temperatures are in the range of 1800°F to 2000°F at full load. In addition to the cameras, an image processor is required. Each FOCUS image processor consists of a custom computer and software that can accommodate up to four imaging cameras. The particle rate (in counts per minute) can be transmitted to a digital control system using analog outputs from the image processor. Using this rate, a unit specific equation is used to estimate unburned carbon as a percent of total ash. These calculations can be performed on the digital control system or data acquisition system.

Figures 1 and 2 are photographs of a camera as installed at Georgia Power Company’s Hammond 4. The image processing unit is shown in Figure 3. A schematic of a typical arrangement associated with the FOCUS system is shown in Figure 4. Table 1 provides information including accuracy, instrument size, and cost as provided by Applied Synergistics.

As of July 1996, the FOCUS system had been installed at six locations in the United States. Testing on the system has been conducted at Hammond Unit 4, Dairyland Power Cooperative’s Genoa Unit 3, Baltimore Gas & Electric Company’s Morgantown Station, and Potomac Electric Power Company’s Brandon Shores.

Figure 1
FOCUS Camera and Air Filter Assembly

Figure 2
FOCUS Camera Attached to Furnace Inspection Door

Figure 3
FOCUS Processing and Display Unit

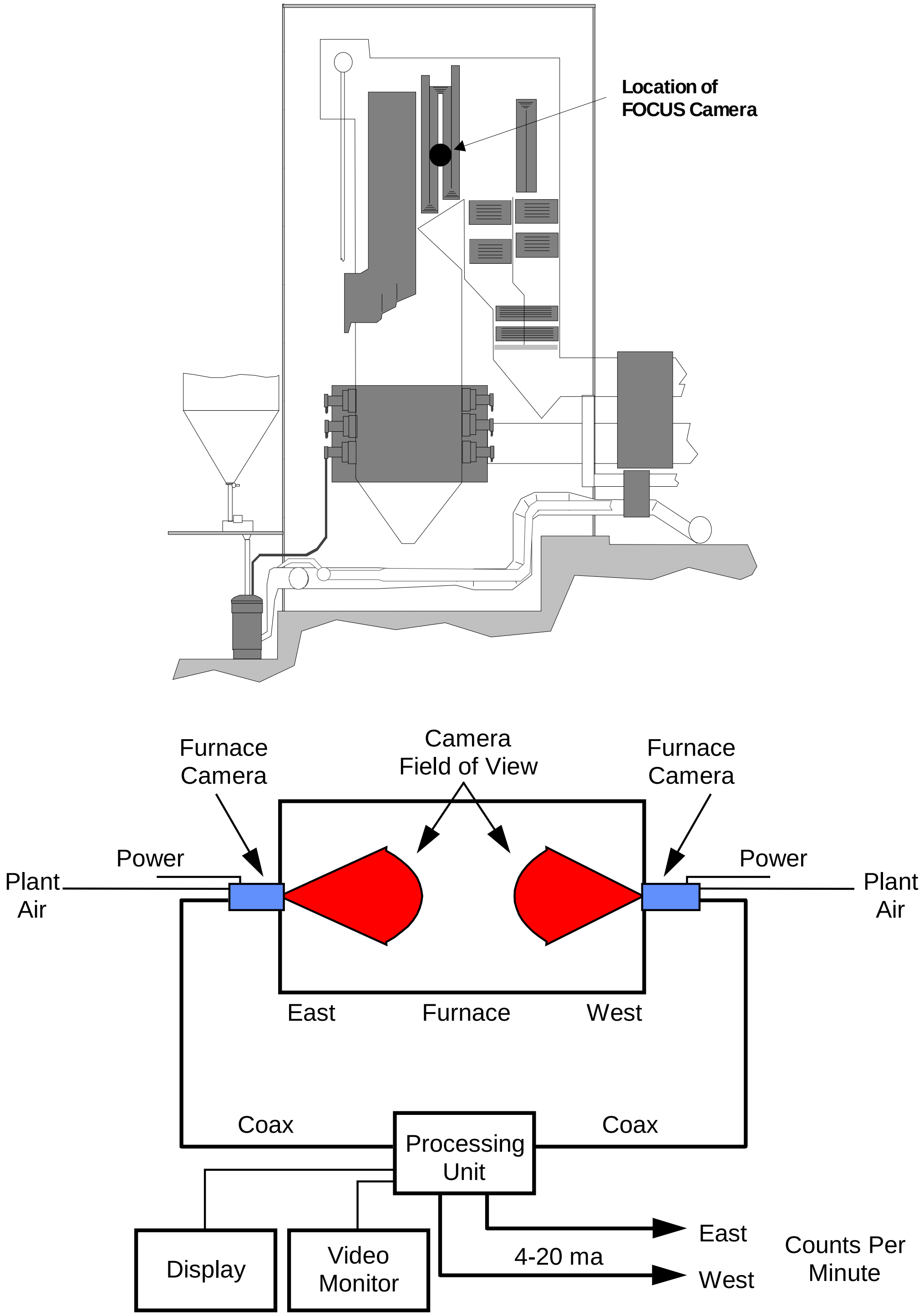

Figure 4
FOCUS Arrangement

Table 1
FOCUS General Information

FOCUS Carbon-in-Ash-Monitor	
Operating Principle	IR Detection
Instrument Size (W x D x H)	1.0’ x 8.9’ x 1.0’ (one camera)
Instrument Weight	
Power Requirements	Camera - 90 - 120 VAC, 24VA Imaging Processor – 90 – 120 VAC, 40VA
Instrument Air	80 – 120 psi
Plant Air	used if instrument air not available
Ambient	
Mobility	instrumentation: medium sampling device: medium
Sample Size	no sample collected
Quoted Range	
Quoted Accuracy	1.1% standard error of LOI
Analysis Display	bar graph of counts for 24 hour period; counts per minute which can be converted into LOI
Response Time	less than 1 minute
Normal Maintenance	• Replace compressed air filters at a frequency dependent on plant air quality
Cost	$40,000 - $80,000 depending on number of cameras
Contact	Mr. Randy Carter Applied Synergistics, Inc. 19206 Forest Road Lynchburg, VA 24502 (804) 385-6102 phone (804) 385-0714 fax

Installation

A purchase order for a FOCUS system was placed with Applied Synergistics (ASI) during June 1995. The dual camera system was delivered to Georgia Power's Plant Hammond during July 1995 and installed that month by the vendor. The major activities associated with the installation of this instrument included:

- Camera site selection. Based on the vendor's inspection of the furnace considering available furnace access points and combustion conditions, it was decided that the furnace cameras would be installed on two small (6" x 8") observation doors near the top of the furnace. Factors to be considered in the placement of the cameras include:

  Furnace temperatures below the combustion temperature of carbon but sufficiently high that the carbon laden particles radiate at higher levels than the carbon free ash and surroundings (gas and structure), typically 1800°F to 2000°F.

  View not blocked by furnace internals, such as slag screens or superheat/reheat panels.

- Fabrication of observation door mounts. These mounts were necessary so that the cameras could be securely fastened to the observation doors.

- Routing of plant air. Air hoses were used to provide air to the two cameras. ASI provided the necessary filters and hand valves. The air is used for cooling and purging of the camera.

- Routing of coax cable. Coax cable was installed from the cameras to the processor. This processor was installed in an instrument room adjacent to the boiler.

- Calibration of the instrument. The FOCUS system provides a signal to the DCS representing a rate (in counts per minute) at which hot unburned combustible particles traverse the field of view of the camera. This rate must be converted in the DCS to a value representing fly ash unburned carbon level. In order to develop the relationship between counts per minute and LOI, several representative ash samples must be collected and analyzed. ASI recommends that ash samples be collected and analyzed for three load levels and three oxygen levels at each load. At Hammond, isokinetic, multi-point sampling at the precipitator inlet was used to collect the representative samples.

Overall, the installation was very straightforward with the major consideration being the determination of a suitable camera location and calibration of the instrument so that LOI can be calculated.

Comparison to Manually Collected Samples

Testing of the FOCUS system was conducted on Hammond Unit 4 during July 20 and 21, 1995 and February 8 and 9, 1996. As discussed previously, the FOCUS system provides outputs representing the counts per minute of "glowing" ash detected at the elevation of the cameras. To obtain percent LOI or carbon, this signal must be transformed using an ASI supplied equation, coefficients of which should be determined by testing. Therefore, the first round of testing (July 1995) had two purposes:

- Determine these calibration coefficients.

- Determine how well the FOCUS system could represent LOI from isokinetically collected samples.

During each of the nine tests conducted during July 1995, 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 (300, 400, and 500 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 receives roughly 70% of the fly ash collected by the precipitator. Because the FOCUS provides a reading representing the "A" side and "B" side separately, the readings from it were compared to the corresponding duct sample.

As mentioned above, the output of the FOCUS system is a signal representing the rate at which glowing particles are detected in the field of view of the cameras. The assumption is that the greater the particle rate for a given load level, the greater the LOI level. As shown in Figures 5 and 6, this assumption did not hold true for the test conducted at Hammond. For example, for the 500 MW tests, the particle rate decreased with increasing LOI (and though not shown, with decreasing excess oxygen). The standard LOI equation for the FOCUS system is of the form:

$$LOI = \frac{A}{\frac{LOAD}{CPM} + 1} + B$$

where A and B are coefficients determined when calibrating the instrument. After the July testing, ASI provided an equation in this form (based on the results from these tests). The comparison of the FOCUS predicted LOI and the isokinetic LOI is shown in Figures 7 and 8. As shown, using this equation form, the FOCUS was not a very good predictor of the LOI of the isokinetically collected ash samples. According to ASI, the

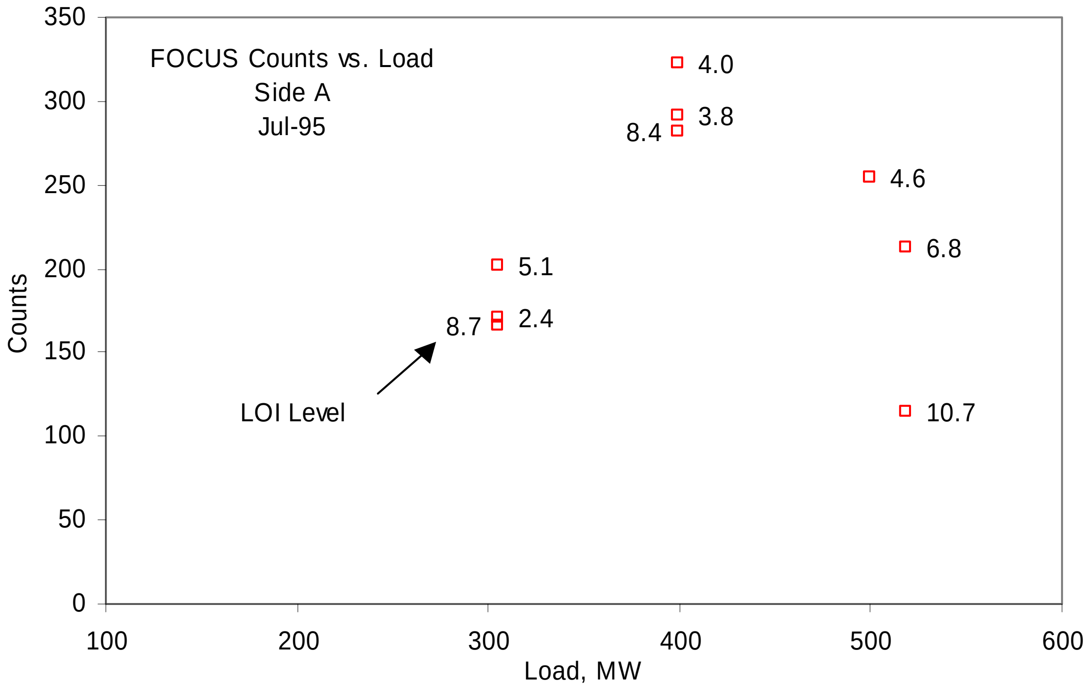

Figure 5
Counts vs. Load and LOI (Side A)

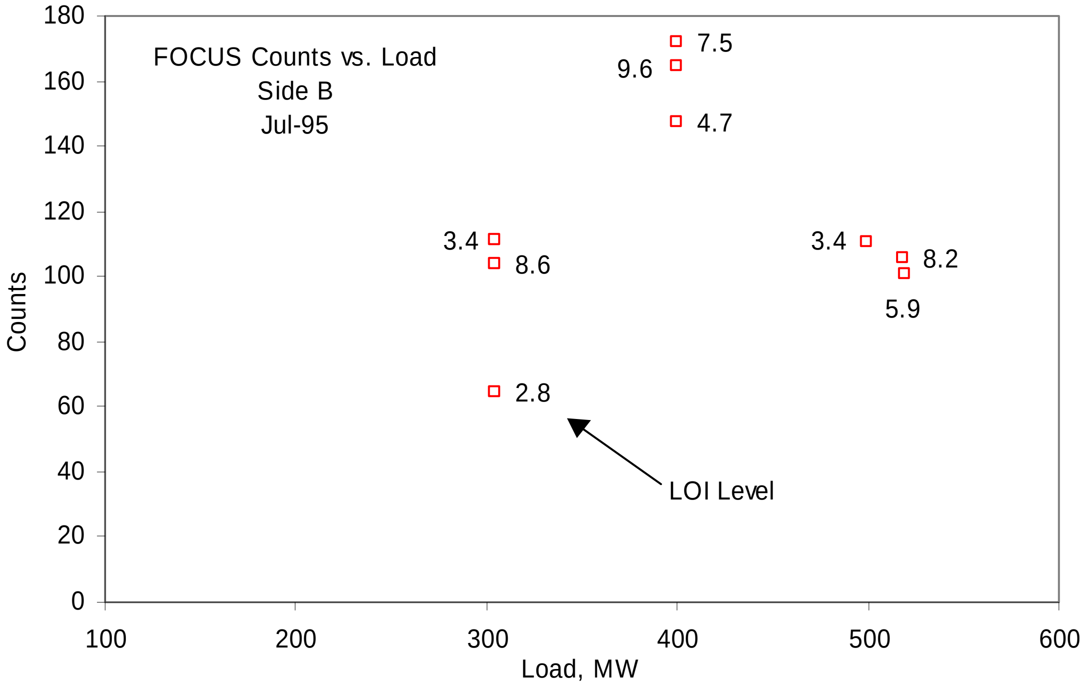

Figure 6
Counts vs. Load and LOI (Side B)

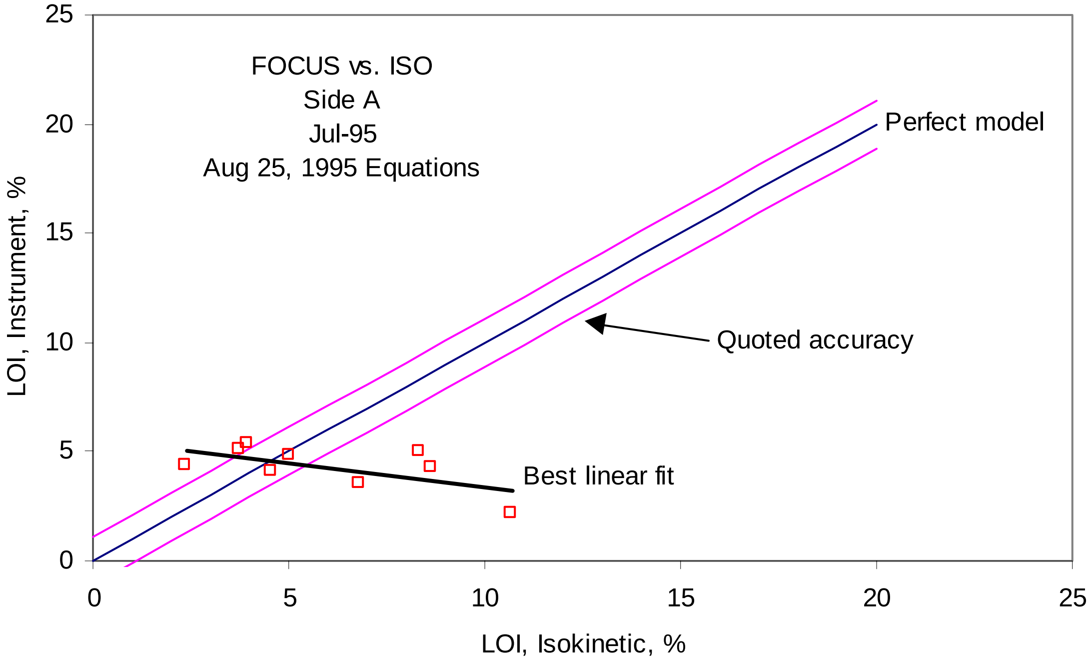

Figure 7
FOCUS vs. Isokinetic Samples (Side A)

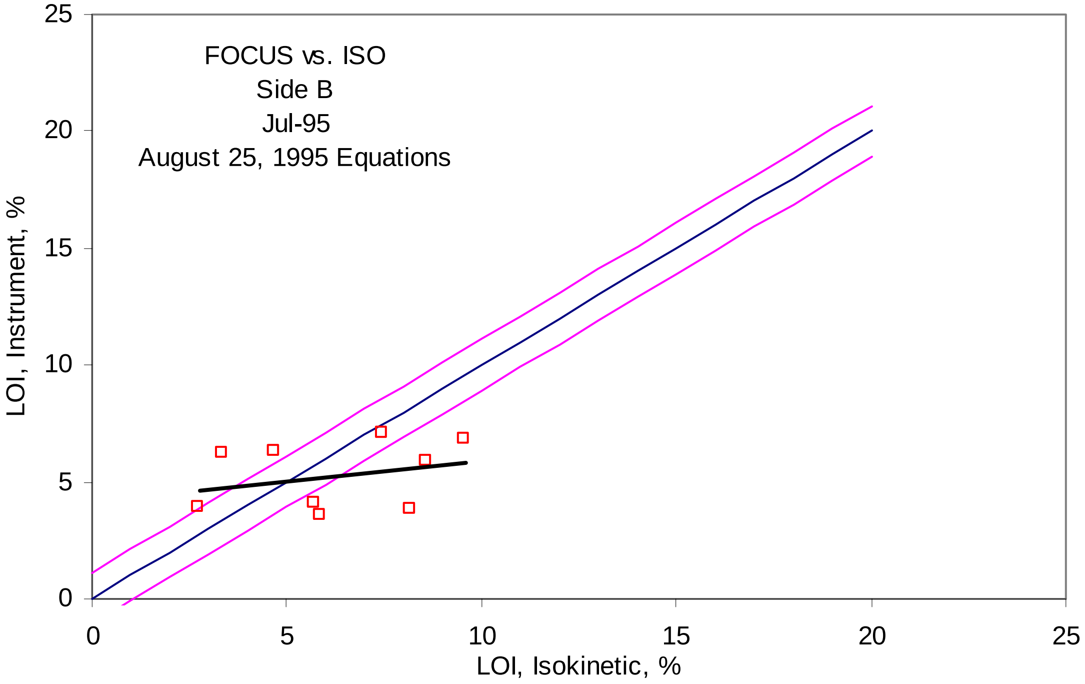

Figure 8
FOCUS vs. Isokinetic Samples (Side A)

relatively poor predictive qualities were the result of low and non-uniform oxygen distributions in the furnace. The upper furnace oxygen distribution determined from previous testing at Hammond is shown in Figure 9. Although combustion imbalances could have certainly been a factor, it is our opinion that it is exactly under these conditions when a reliable LOI indication is most needed. According to ASI, the FOCUS system would be responsive to changes in LOI when the oxygen level at the position of the cameras is more uniform.

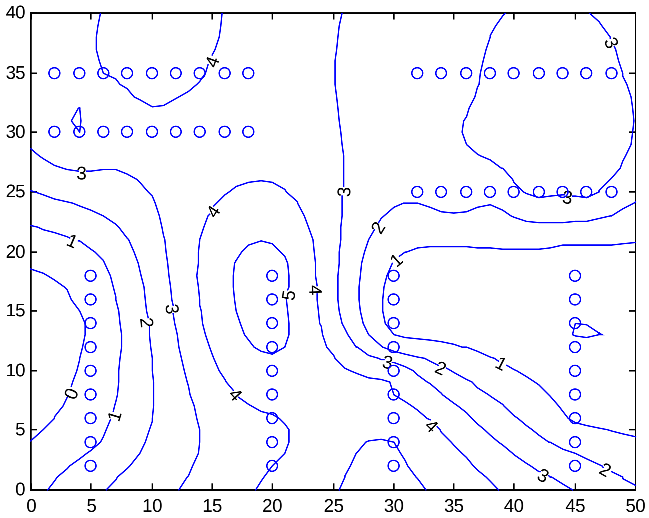

Figure 9
Example Oxygen Distribution at Top of Furnace

It should be noted that in Figures 7 and 8, the FOCUS data is being compared to data to which it has been calibrated and, therefore, the comparison is biased to a more favorable outcome. Similar results are obtained when the FOCUS values are compared to those obtained from the hopper ash samples (Figures 10 and 11).

To compensate for the limited response of the FOCUS system, ASI supplied a second set of equations that included excess oxygen in addition to counts per minute and load:

$$LOI = A + B\left[\frac{\dfrac{1}{\dfrac{LOAD}{CPM}+1}}{O2}\right] + C\frac{1}{\dfrac{LOAD}{CPM}+1}$$

where the coefficients *A*, *B*, and *C* are again determined from testing. The results of using this equation on the July data are shown in Figures 12 and 13. As can be seen, this greatly improved the predictive qualities. However, as also can be seen in these figures, similar results can be obtained from using load and excess oxygen without the FOCUS signal.

A second round of testing of the instrument was conducted February 8 and 9, 1996 at Hammond. The scope of the testing was similar to that conducted during July 1995 with isokinetic and hopper samples being collected. Following these tests and using isokinetic LOI data collected from these tests, ASI supplied a third set of equations to predict LOI as a function of particle counts per minute, load, and excess oxygen. A comparison of the FOCUS predictions and the isokinetic results are shown in Figures 14 and 15. The results are similar to that obtained during July 1995. Also as in July, similar results can be obtained when using load and excess oxygen alone.

It is also informative to apply the previous equation provided by ASI to the data collected during February 1996 (Figures 16 through 19). Results from using the September equations are similar to those obtained with the February equations whereas the predicted values from the August equations (which do not include excess oxygen as an independent variable) show very little correlation with the isokinetic LOI values.

Time Response

When carbon-in-ash monitors are used for control and optimization, timeliness of the response is an important consideration. The response for the FOCUS is shown in Figure 20. During the time period shown, both unit load and excess oxygen varied. Since the FOCUS system does not collect an ash sample, the most influential factor in the time response of the instrument is the elapsed time used to count the particles traversing the camera(s) field of view. As shown, the FOCUS responds very rapidly (~ 1 minute) to changes in operating conditions. However, consideration must be given to the fact that the FOCUS equations include load and excess oxygen as independent variables and therefore any change in these would be reflected in the equation output immediately.

Reliability and Maintenance Aspects

The FOCUS system was installed in July 1995 and has shown a high level of availability. Maintenance items included:

- An East camera count error occurred as a result of slag screen movement. A lens filter was installed and the camera was repositioned.
- The automatic iris arrangement on the East side was also changed to a fixed aperture.

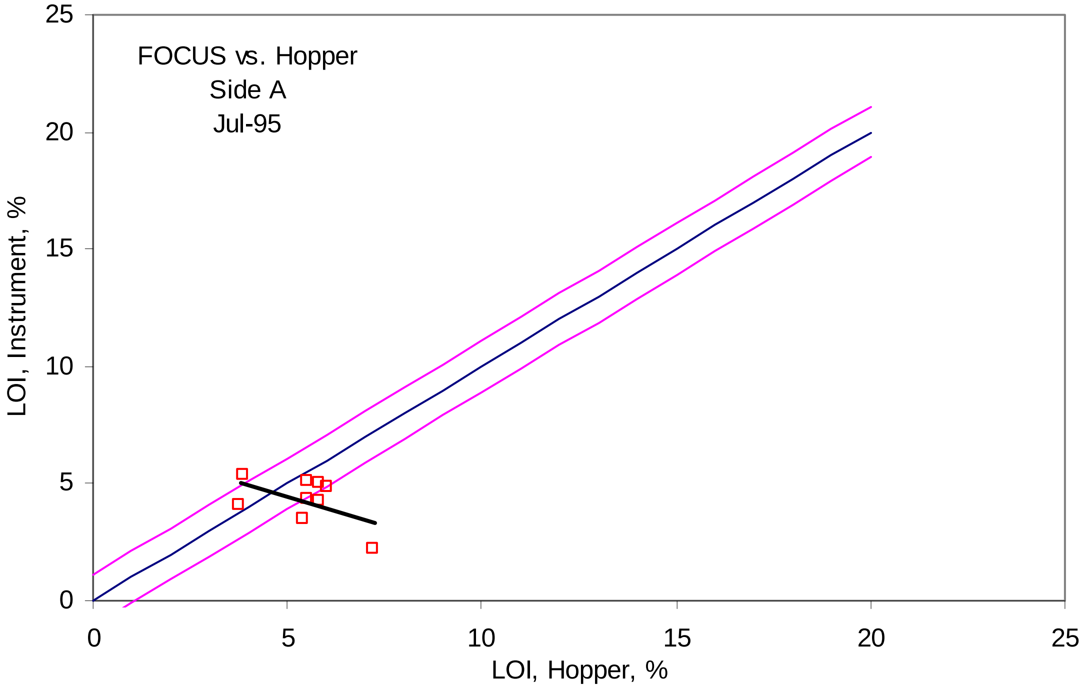

Figure 10
FOCUS vs. Hopper Samples (Side A)

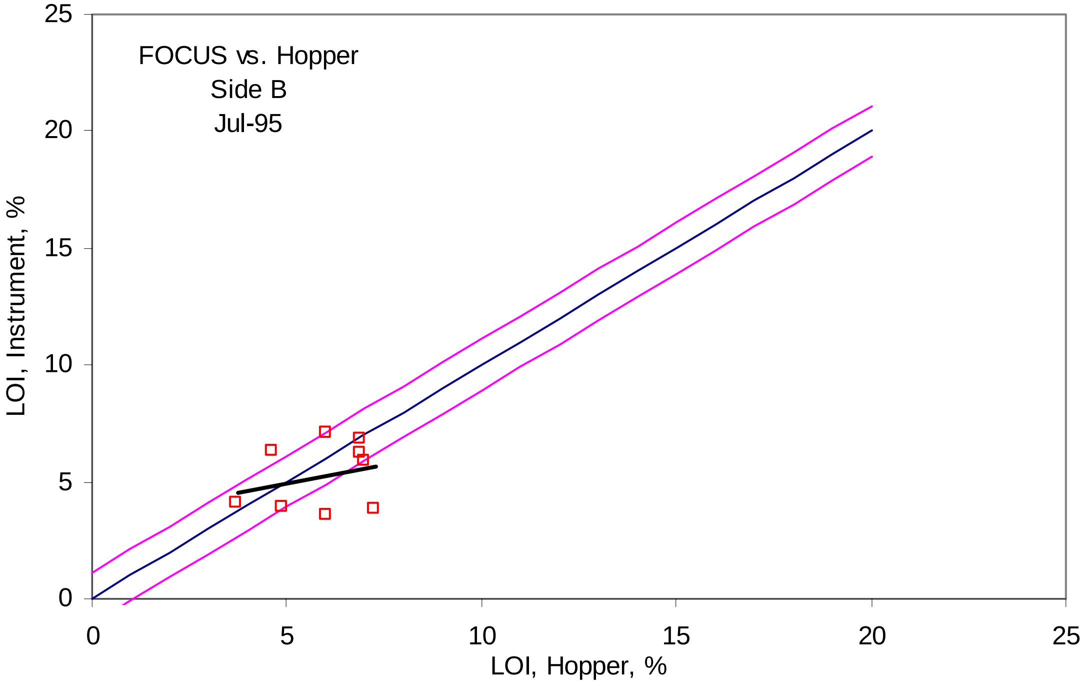

Figure 11
FOCUS vs. Hopper Samples (Side B)

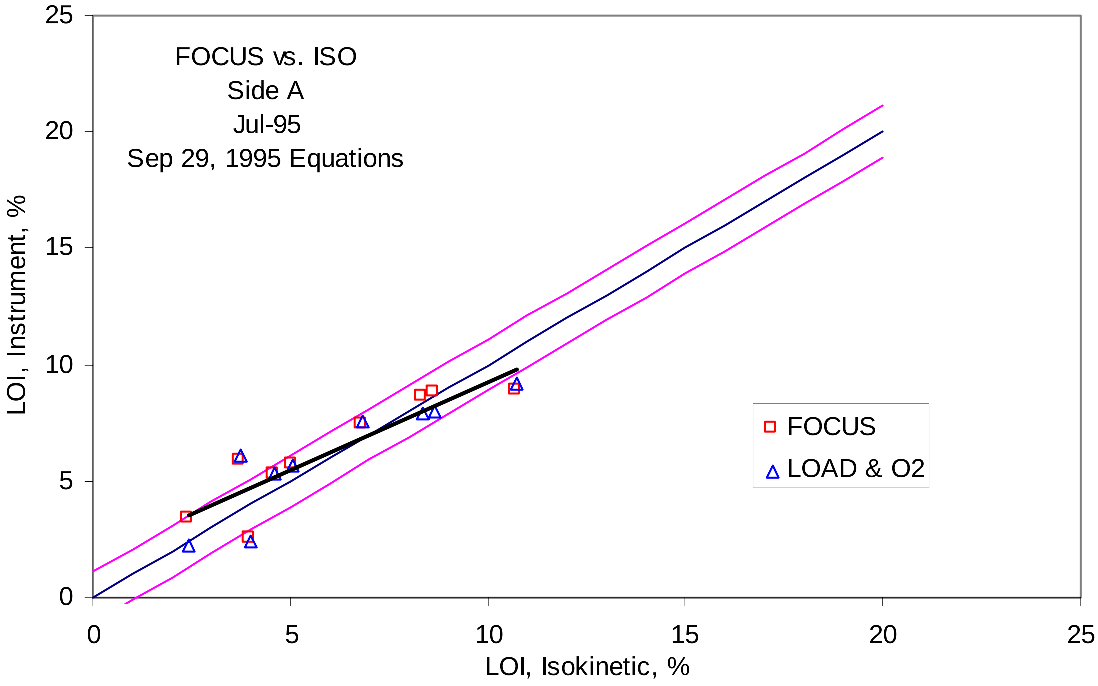

Figure 12
FOCUS vs. Isokinetic Samples (Side A)

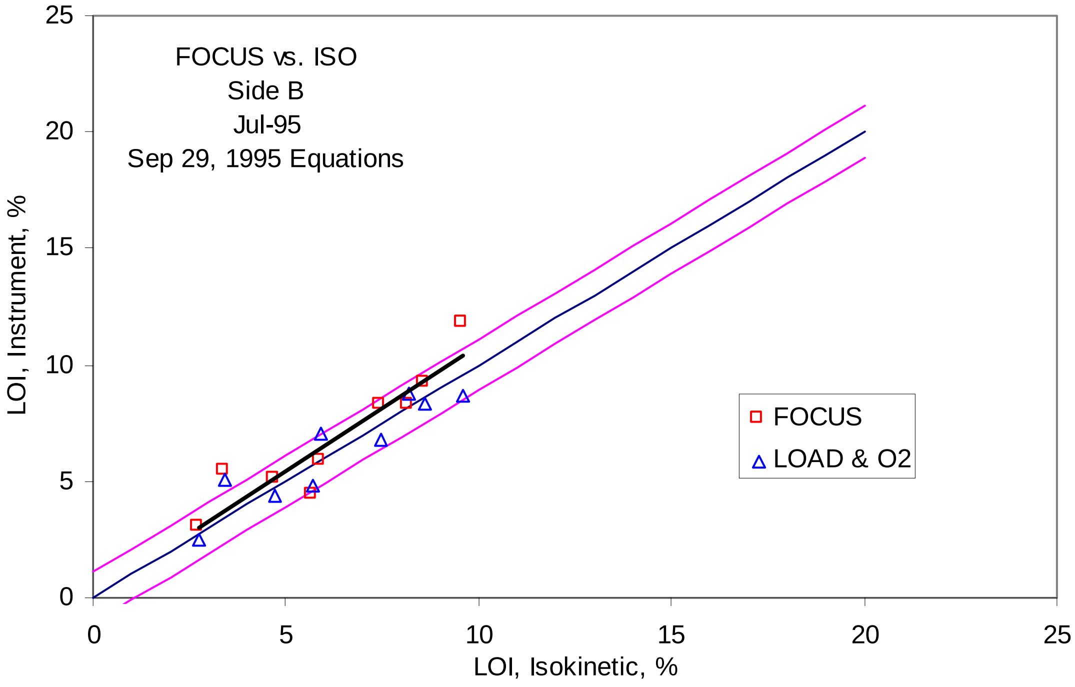

Figure 13
FOCUS vs. Isokinetic Samples (Side B)

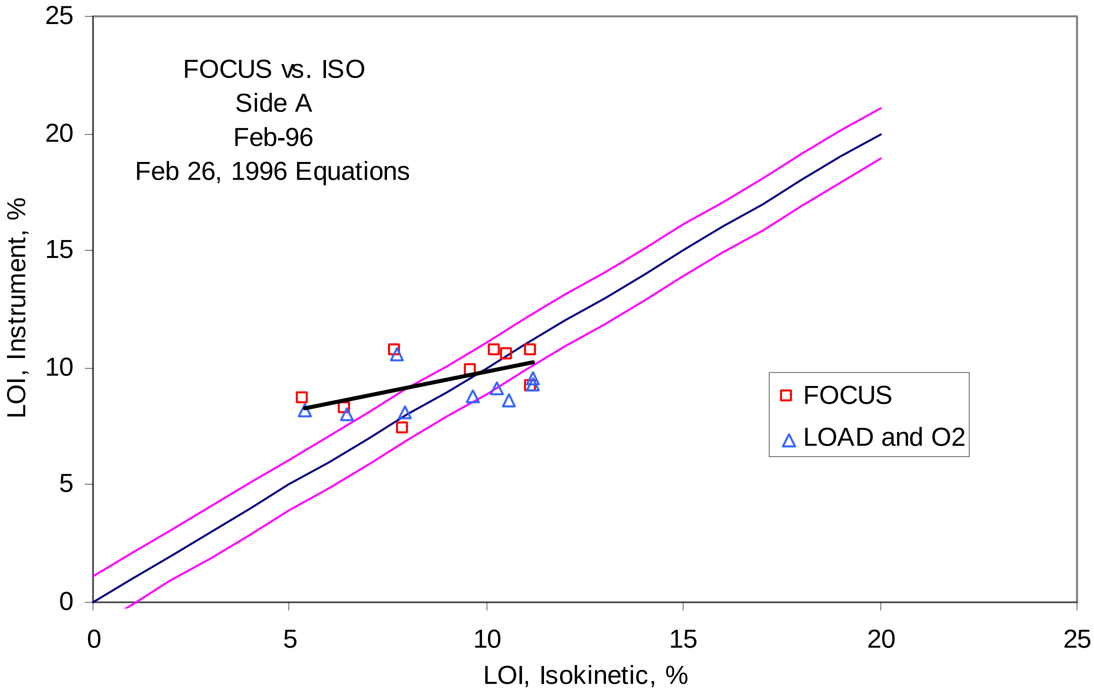

Figure 14
FOCUS vs. Isokinetic Samples (Side A)

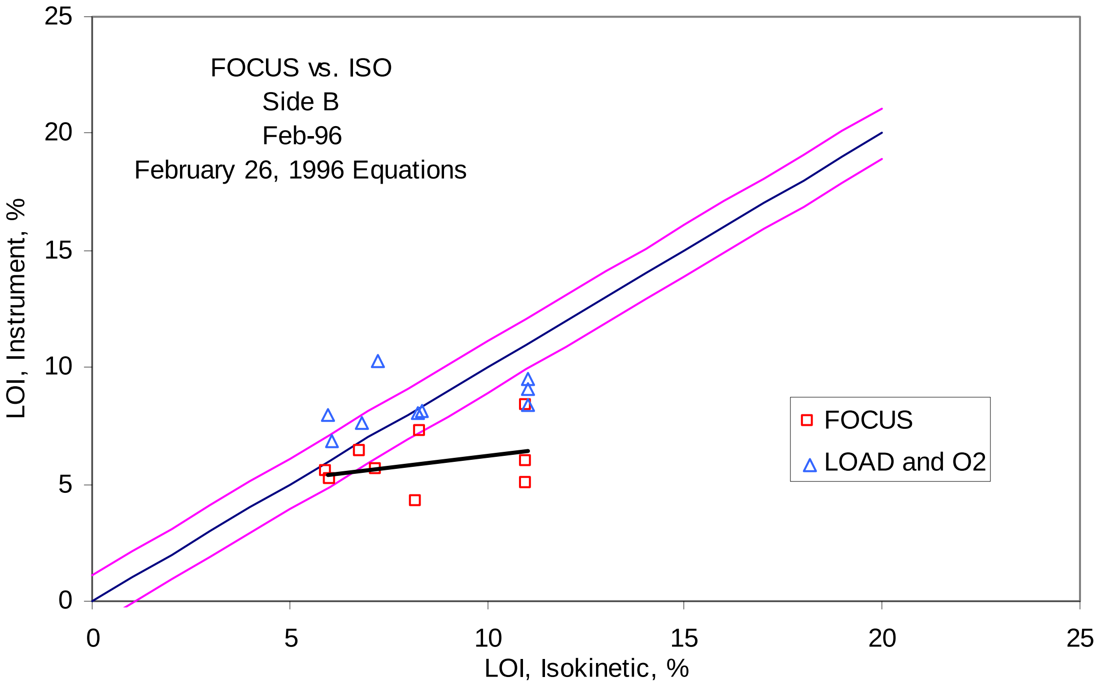

Figure 15
FOCUS vs. Isokinetic Samples (Side B)

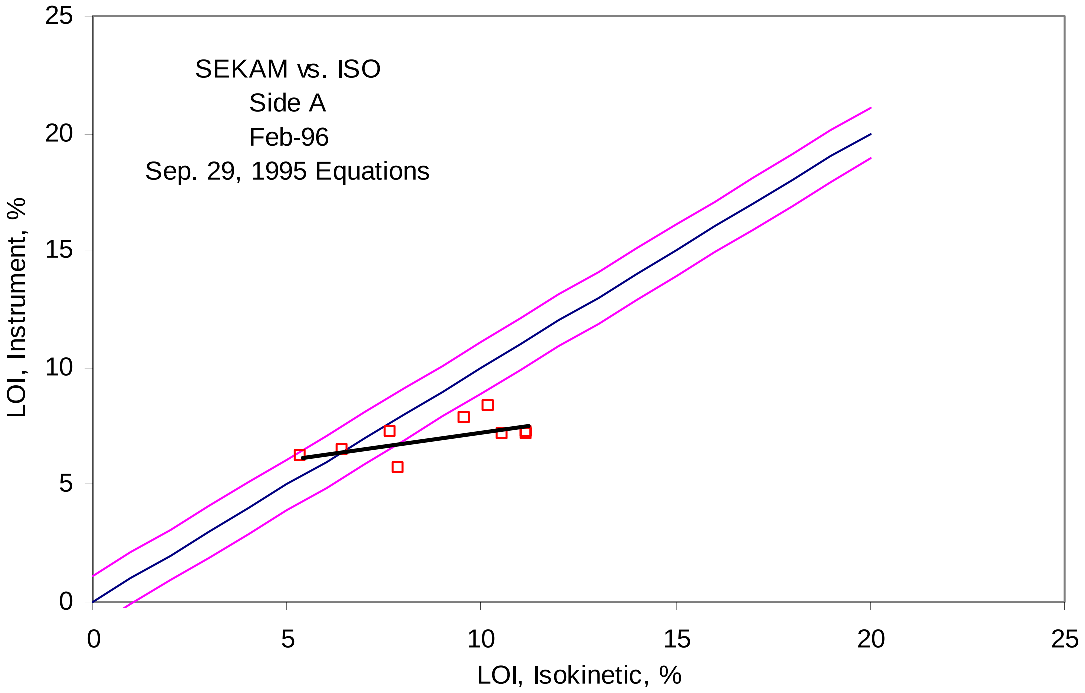

Figure 16
FOCUS vs. Isokinetic Samples (Side A)

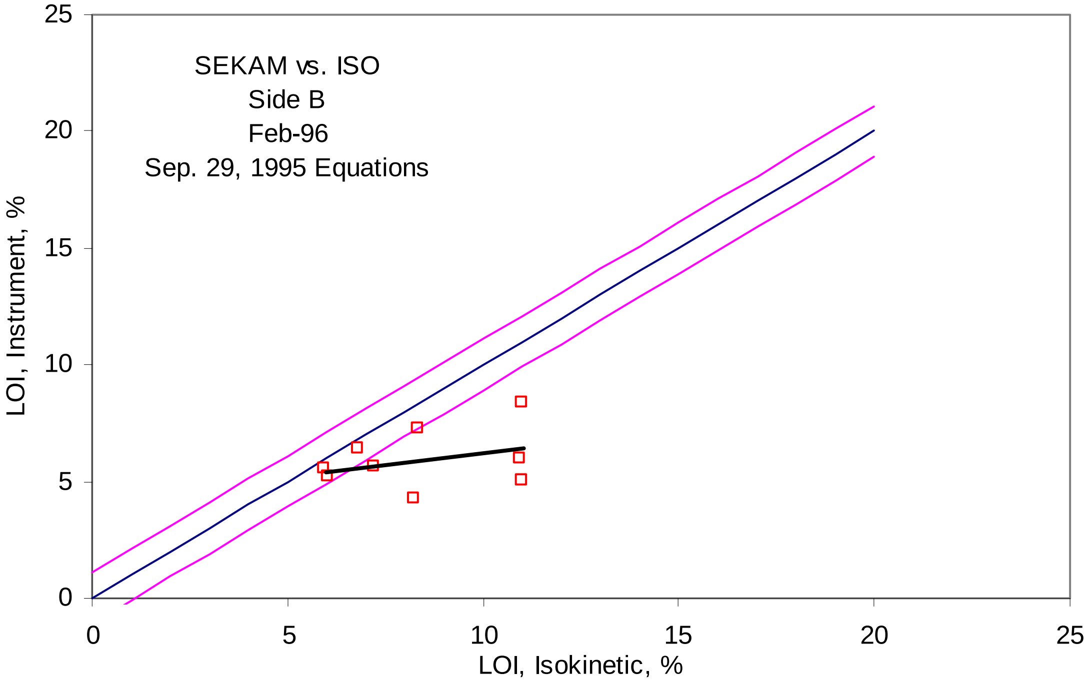

Figure 17
FOCUS vs. Isokinetic Samples (Side B)

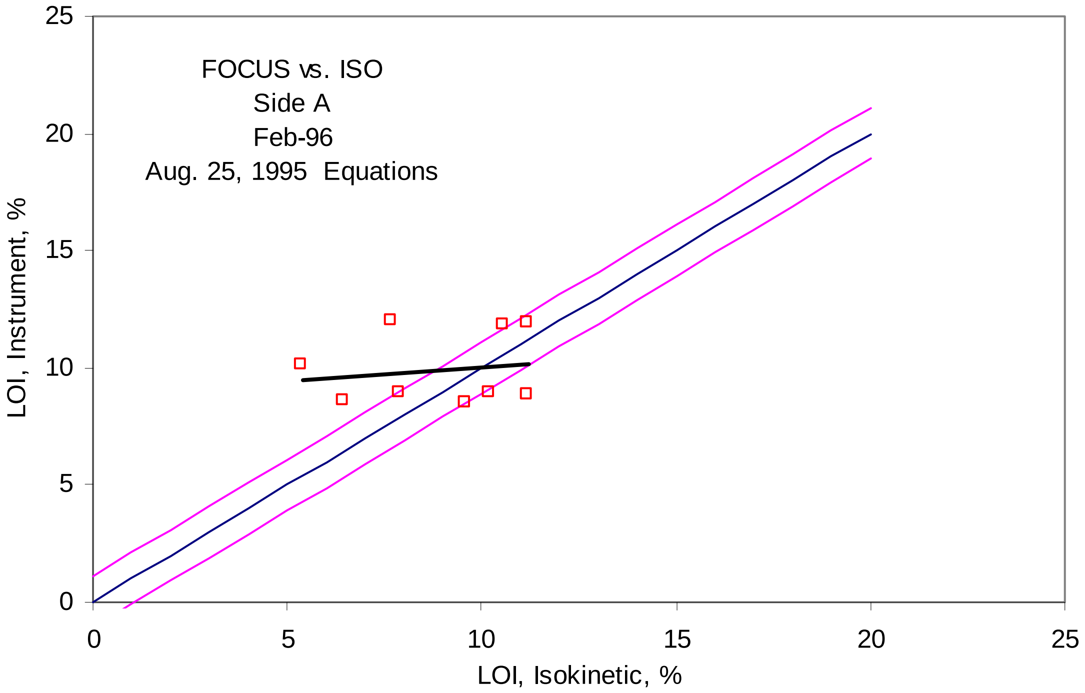

Figure 18
FOCUS vs. Isokinetic Samples (Side A)

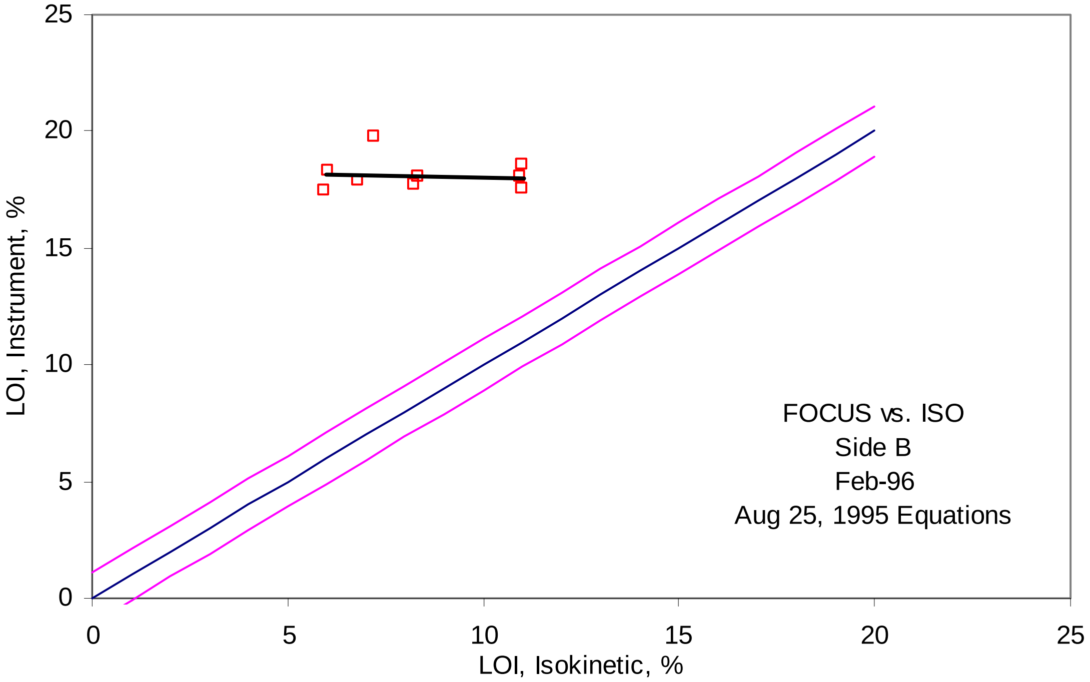

Figure 19
FOCUS vs. Isokinetic Samples (Side B)

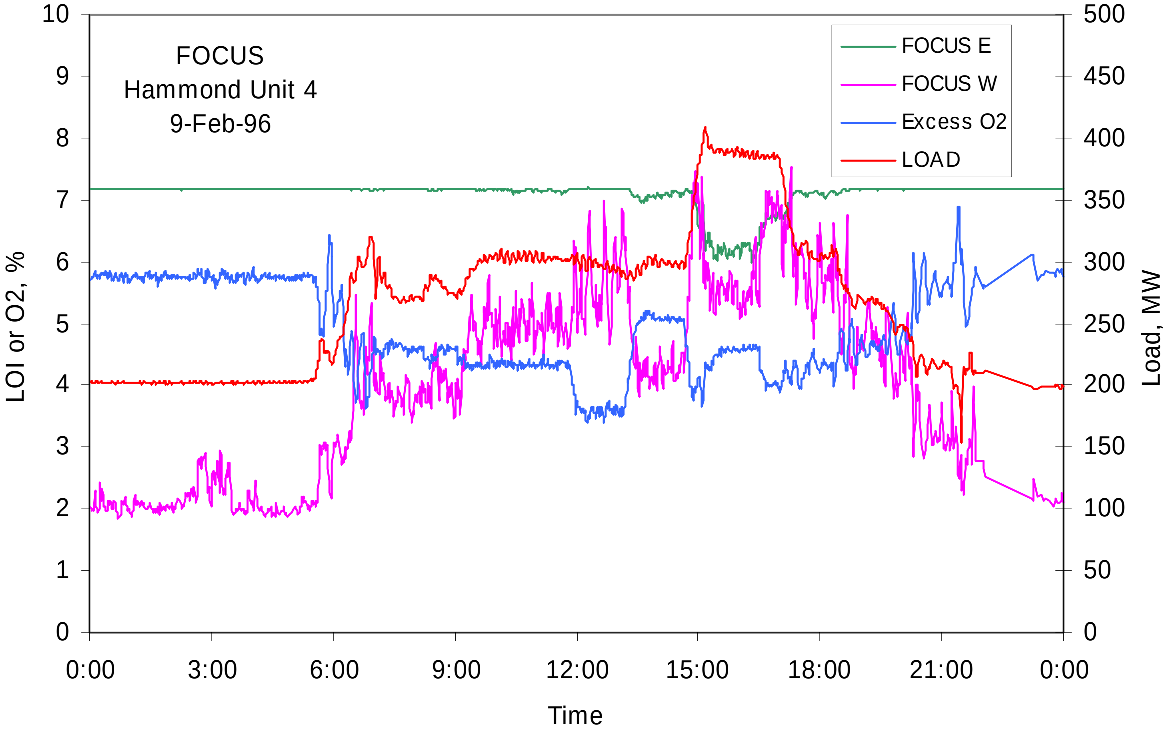

Figure 20
FOCUS Time Response

RCA

Mark and Wedell (M&W), a Danish engineering firm, began development of the Residual Carbon Analyzer (RCA) in 1980. The instrument has been used for determining the quantity of carbon-in-ash for combustion control, for controlling mill performance, and for sorting fly ash. This on-line analyzer has mostly been used in European industrial and utility applications. The first installation in the U.S. was at Alabama Power Company's Plant Gaston Unit 4. As of June of 1996, there were a total of 135 instruments installed worldwide.

The RCA's operating principle is based on the infrared reflective properties of fly ash. A sample of ash is extracted isokinetically from the flue gas duct and placed into a sampling glass. The ash is then exposed to infrared light whose reflection is used as a means of estimating the residual carbon content in the sample. After the residual carbon content has been measured, the sample can either be blown back into the duct or deposited into the system's built-in sampling bottle. At full load, a new sample is collected and analyzed typically every two to three minutes.

The unit is designed for either hot-side or cold-side placement before the electrostatic precipitators. The company prefers the system to be installed into a vertical duct, however the unit can be adapted for horizontal use if necessary. The RCA is also capable of providing simultaneous readings for split ductwork upstream of the precipitators. A major difference between this extractive system and the others currently on the market is that the bulk of the analysis electronics is incorporated into the sampling apparatus that is attached to the duct. This design feature removes the need to provide insulated and heat traced sample line from the sample duct to the control unit, thus potentially, reducing cost and problems resulting from the sampling apparatus. Also, for multi-point systems, the overall sampling rate can be increased since the analysis/sampling units are not "time shared" between sample points. However, overall cost of the installation can increase since multiple units of the analysis/sampling units are required.

A photograph of an RCA installation is shown in Figure 1 and a functional schematic of the RCA is shown in Figure 2. Performance aspects such as unit accuracy, sample size and mobility are provided in Table 1. This data is based on information received in company marketing material and system specifications.

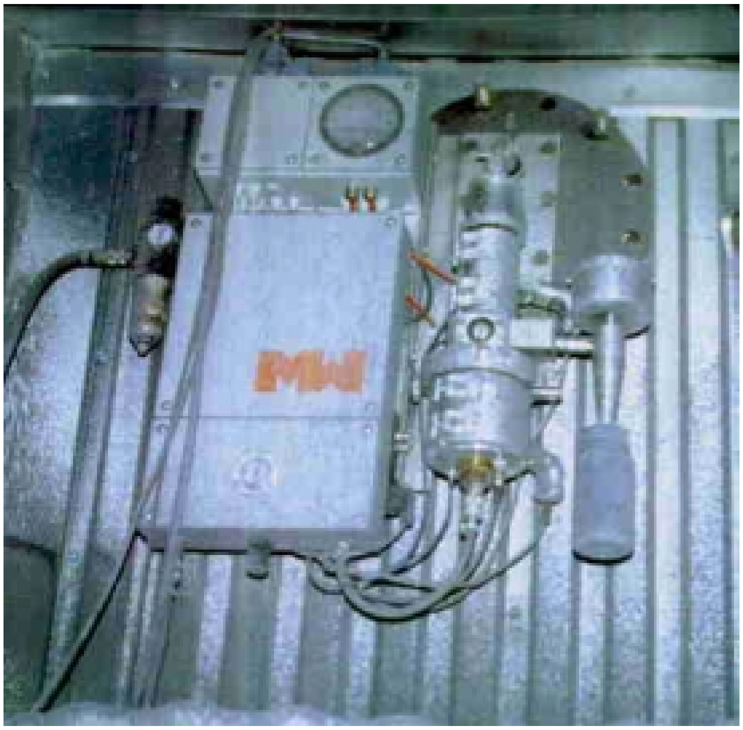

Figure 1
RCA Monitor

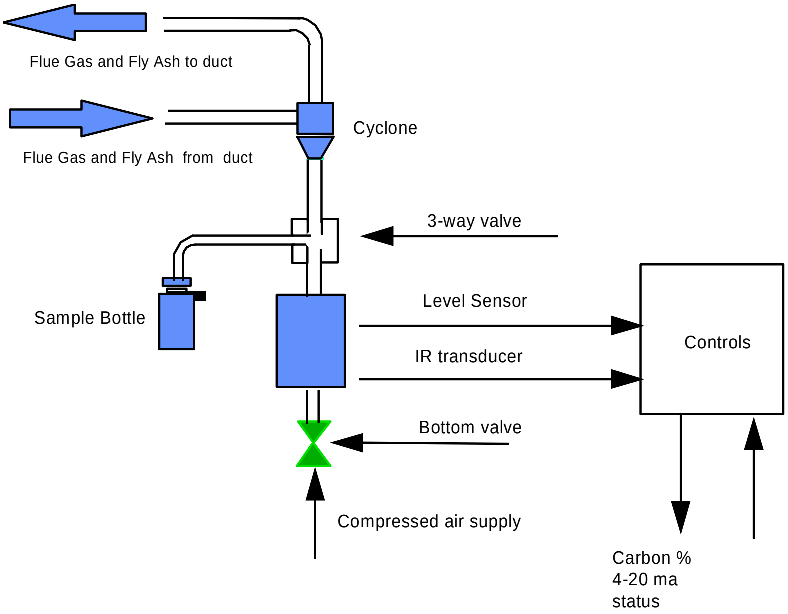

Figure 2
RCA Schematic

Table 1
RCA General Information

RCA Monitor	
Operating Principle	Reflection of infrared light
Instrument Size (W x D x H)	2.6’ x .75’ x 2.5’
Instrument Weight	Ash sampler – 35 kg (77 lb) Control unit - 40 kg (88 lb)
Power Requirements	110 V, 60 Hz, 400 W
Instrument Air	not required
Plant Air	5 bar (74 psi) minimum
Ambient	0% - 95% RH, non-condensing Control cabinet - 5°C - 45°C (41°F - 113°F)
Mobility	instrumentation: medium sampling device: medium
Sample Size	~ 18 grams
Quoted Range	0 – 20% carbon by weight
Quoted Accuracy	± 0.5%
Analysis Display	choice of current or time average % carbon or % LOI
Response Time	typically 3 minutes but dependent on ash loading
Normal Maintenance	• clean/replace glass tube - 3 months • clean ejector & nozzle - 3 months • clean piping & cyclone - 6 months • replace o-rings - 6 months • recalibrate - 6 months
Cost	$43,000 - $45,000 for single point system $73,000 - $75,000 for dual point system
Contact	Mr. Johnny Nielsen M&W Ash Systems, Inc. 2160 Kingston Court, Suite H Marietta, Georgia 30067 (770) 984-2770 phone (770) 984-9901 fax

Installation

A dual-sample point Mark & Weddel Residual Carbon Analyzer (RCA) was installed on Alabama Power Company's Gaston Unit 4 during February 1996. The purchase order for the instrument was placed during December 1995. The sampling units were installed in vertical duct runs prior to the air heaters (Figure 3). The flue gas temperature at this location is approximately 700°F.

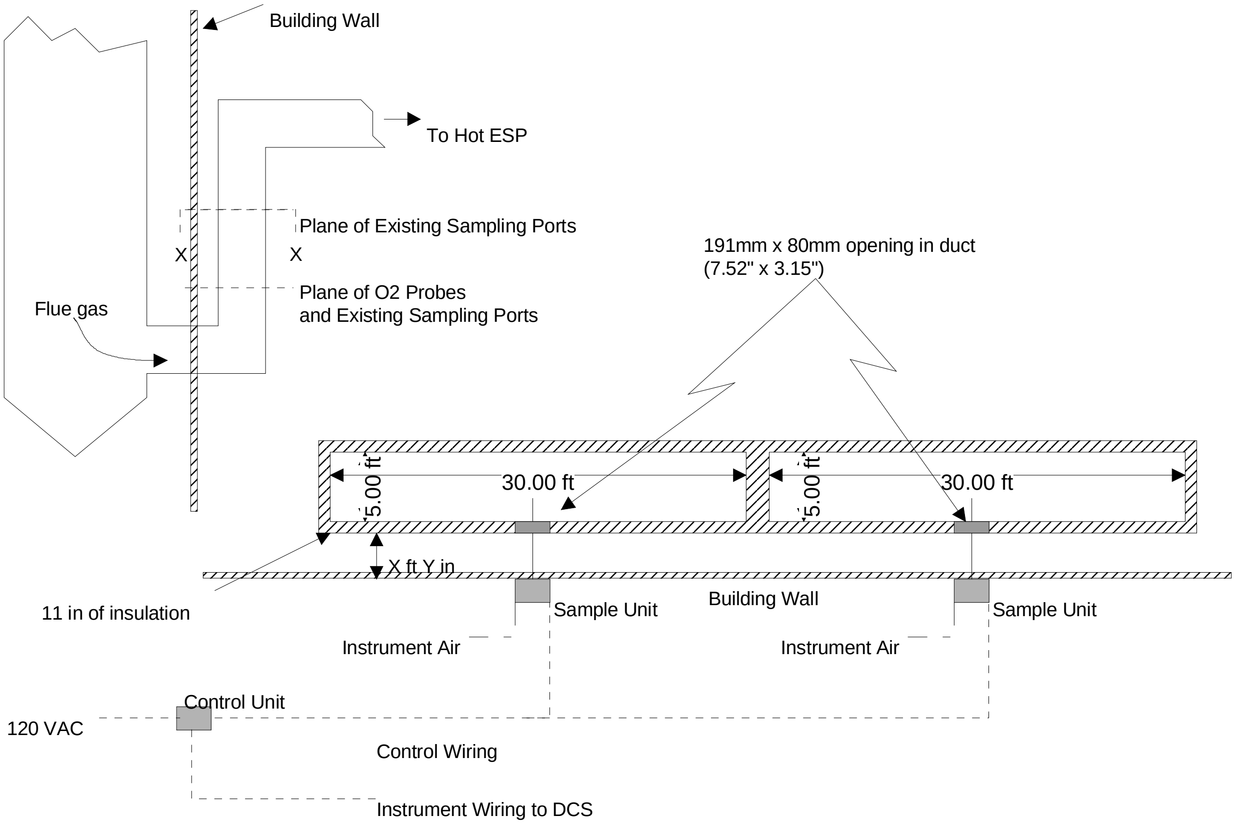

Figure 3
Installation of RCA at Gaston 4

The activities involved with the installation were:

- Installation of the RCA sampling units on the vertical duct. The required RCA port opening is larger than what was available at Gaston (this is primarily the result of the RCA collecting and discharging ash from the same port). To accommodate the sampling units, custom ports were installed.

- Supply temporary plant air and power to the instrument. Existing local outlets for air and power were utilized.

- Addition of input points to the DCS. Two 4-20 ma signal lines, representing the "A" and "B" sides, were wired from the RCA to the DCS field wiring termination cabinets located near the unit control room.

- A vortex cooler was installed on the control unit. As a result of high ambient temperature (110°F) at the location where the control cabinet was installed, cooling of the cabinet was required.

- Calibration of the instrument. The instrument is calibrated for different coal types by removing collected ash samples from the analysis cell, having the samples lab analyzed, calculating a correction factor, and then installing the new correction factor in the control unit.

Because the RCA does not transport the collected ash to the control unit for analysis, no heat-traced / insulated sample line was required.

Comparison of RCA to Manually Collected Samples

Testing of the RCA system was conducted at Plant Gaston on August 27 and 28, 1996. Seven tests were conducted representing three load levels (135, 200, and 270 MW). During each of the seven tests, composite duct samples were collected from the flue gas stream at the air heater inlet – one each from the “A” and “B” side of the precipitator. The results from the average, “A”, and “B” is shown in Figures 4, 5, and 6, respectively. As shown, the “A” side did a better job than the “B” side of representing the corresponding isokinetic sample. This difference in performance is likely the result of the RCA collecting a sample not representative of the manually collected ash.

Inherent Accuracy

Accuracy of the M&W instrument was further evaluated by placing ash samples with known carbon content directly into one of the two sample units for analysis (side “A”). Inserting samples affords the opportunity to test the response of the instrument when coal changes. According to the manufacturer, calibration coefficients in the RCA should be changed when there is a change in fuel supply to the furnace.

The results of this testing are provided in Figure 7. As shown, the RCA understated the lab analysis reading for all the Gaston ash samples. As also can be seen, the RCA readings did not correlate well with the LOI levels of the ash samples from the other sites. This low correlation may be expected since different coals are utilized at these plants.

Time Response

The response for the RCA as a result of changes in load and excess oxygen is shown in Figure 8. As shown, the total response time of the RCA to these changes was relatively fast for an extractive system with the total time response being in general less than 15 minutes at the loads shown. For greater loads, the response time is reduced whereas for lower loads, the response time is extended. For this particular day, the “A” and “B” sides responded to unit changes similarly. The spikes shown in the RCA plots (particularly the “A” side) are the result of the analyzer not collecting sufficient ash within a timeout period, and the RCA sending a 20% LOI reading to the DCS. The RCA is capable of performing averaging of the several readings, possibly preventing these peaks, but lengthening the response time correspondingly.

Reliability and Maintenance Aspects

The RCA analyzer was installed on Gaston Unit 4 during February 1996. In general the unit operated reliably and without major problems. During the period it was in operation (1Q 1996 through 1Q 1997), other than cleaning the glass sample cell periodically, no maintenance was required. Currently (September 1997), primary technical support is provided from Denmark, however, M&W has indicated that it intends to provide support from the U.S. as the market develops.

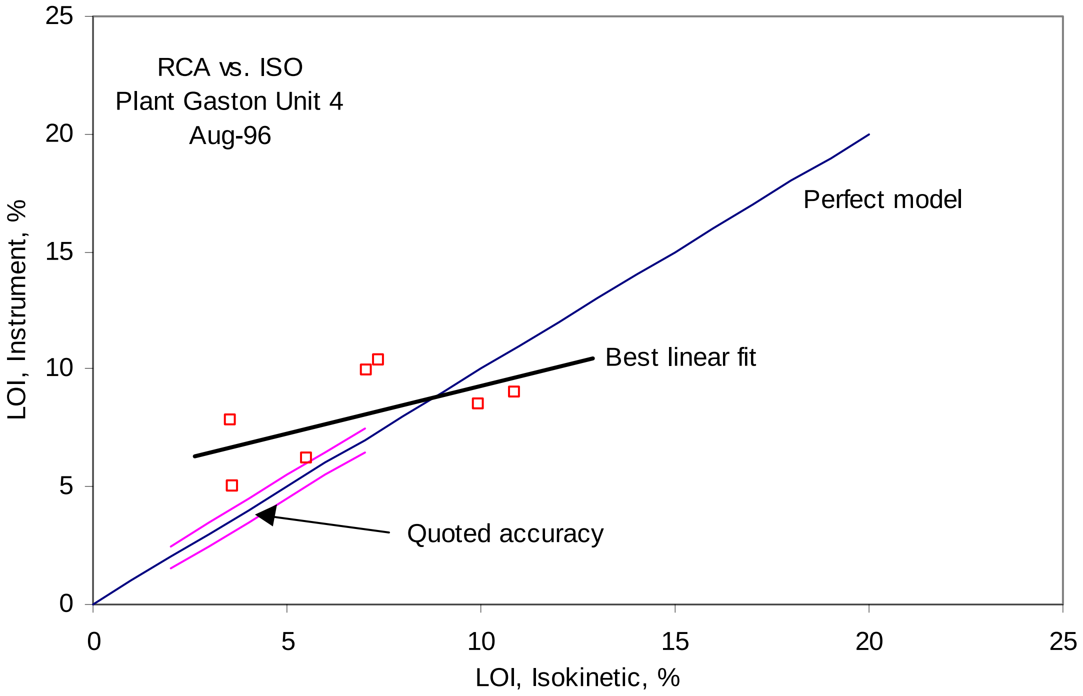

Figure 4
RCA vs. Isokinetic Samples – August 1996

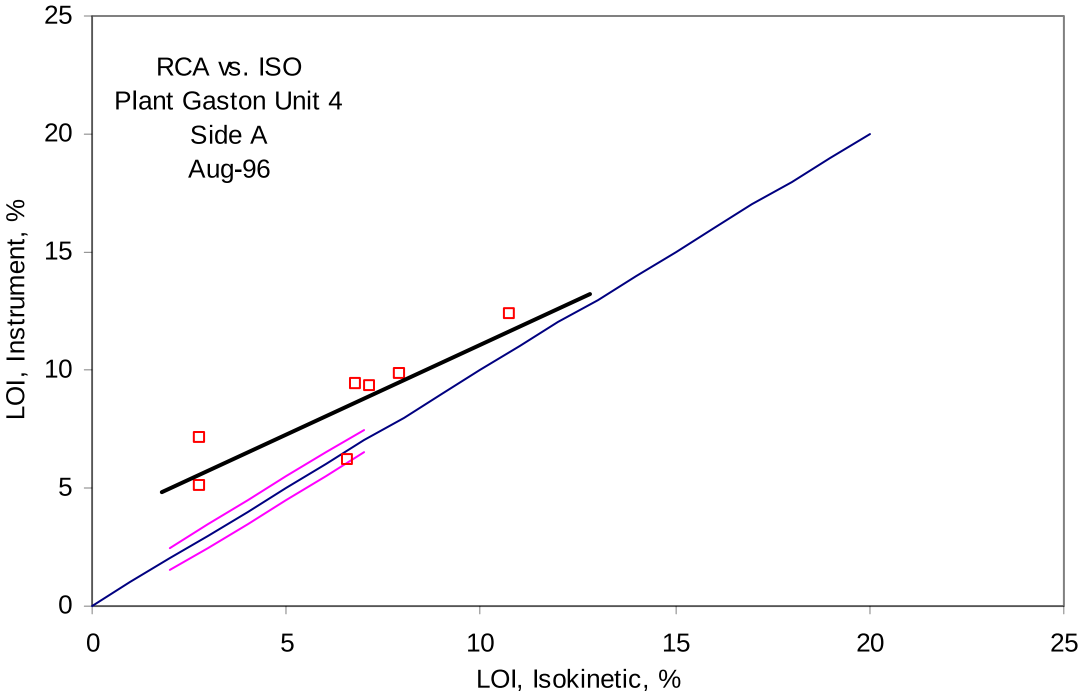

Figure 5
RCA vs. Isokinetic Samples (Side A)

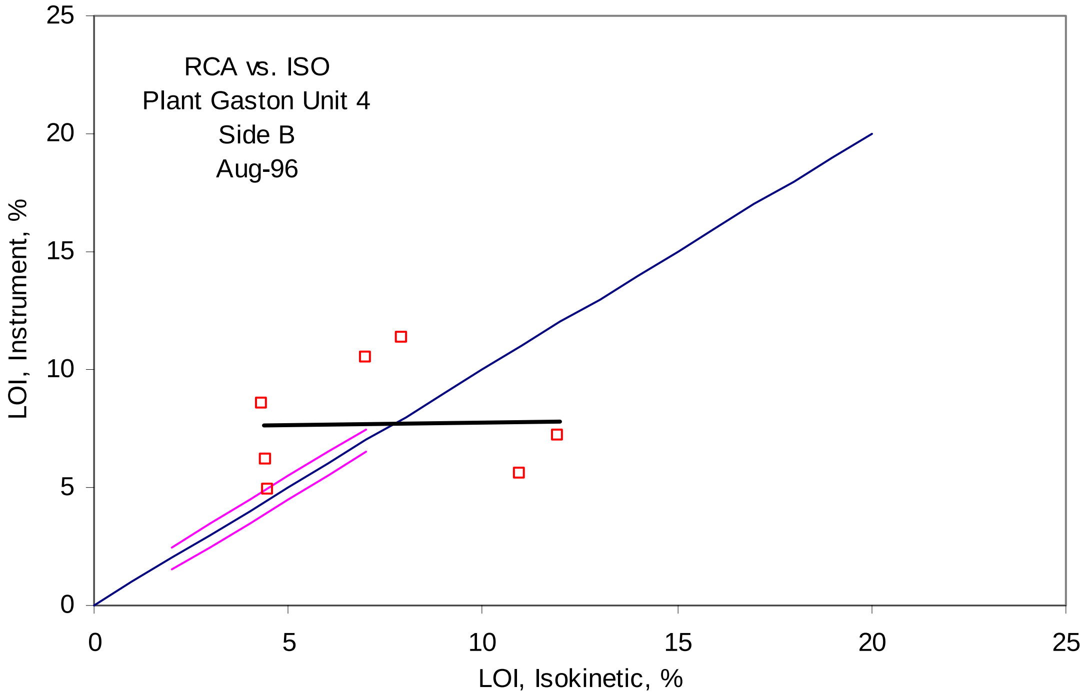

Figure 6
RCA vs. Isokinetic Samples (Side B)

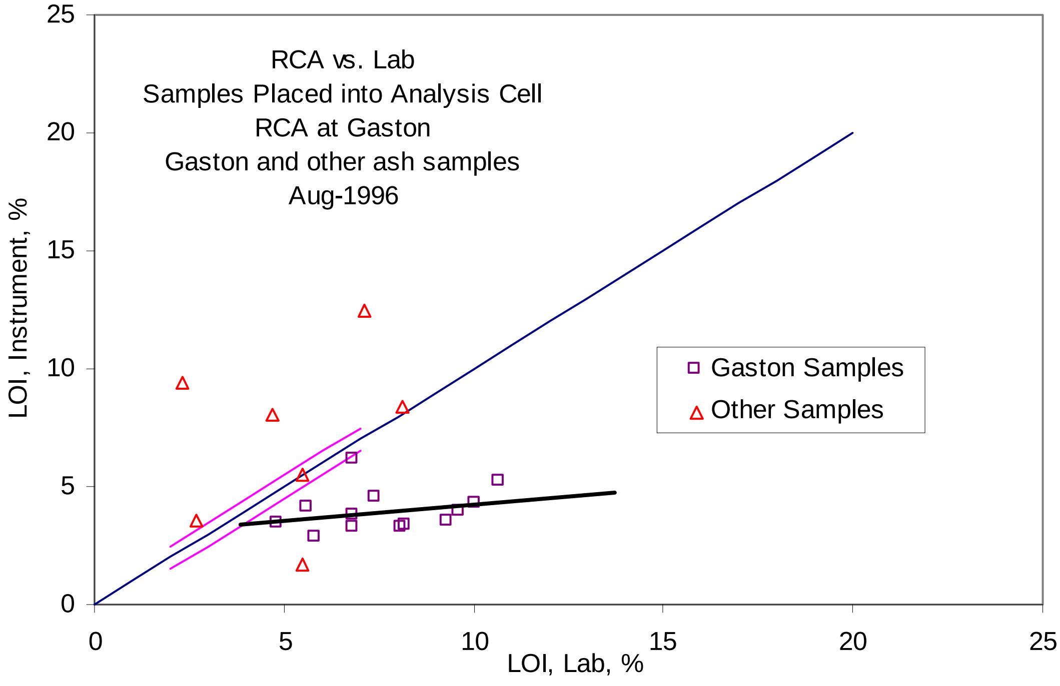

Figure 7
RCA Inherent Accuracy

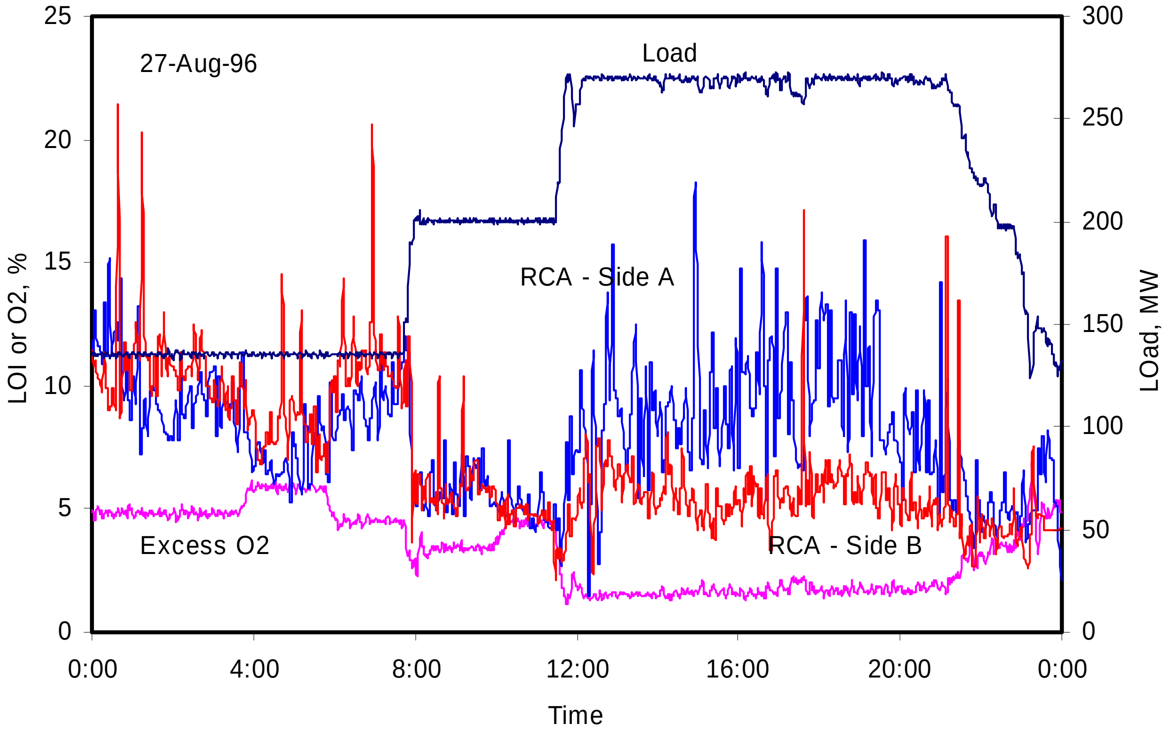

Figure 8
RCA Time Response

SEKAM

The SEKAM on-line carbon-in-ash monitor was developed by the U.K.'s Central Electric Generating Board (CEGB) during the 1980s. Ownership of SEKAM (Sturtevant Engineering Kajaani Ash Monitor) was later transferred to Sturtevant Engineering and now resides with Clyde Pneumatic Conveying. Commercial production of the current monitor began during 1990. As of June 1996, a total of 40 SEKAMs have been installed worldwide. In the United States, the system has been installed at four locations including Georgia Power Company's Plant Hammond Unit 4, Carolina Power and Light's Roxboro Station, PEPCO, and on a fluidized-bed combustion unit at AES Thames in Connecticut.

In the SEKAM instrument, ash is extracted from the flue gas stream using multiple sample probes (Figure 1) and exhauster. Four or more probes are recommended. Super-isokinetic collection and multiple point samples are necessary on this instrument because the relatively large ash sample (relative to other extractive systems) required by this instrument. The flue gas/ash mixture is transported via insulated and heat traced lines to a cyclone separator that collects the entrained ash (Figure 2). Two slide valves allow the collected ash to be deposited into the rectangular glass measurement cell known as a Kajaani cell, that is positioned between two capacitance sensors (Figure 3). The Kajaani cell was developed by the Finnish firm Kajaani, Ltd. for determining the carbon content of ash in precipitator hoppers. Ash passes through the vertical glass chamber on a plug flow basis rather than a batch basis. The measurement principle of the SEKAM is based on the capacitance of the ash sample and how this capacitance varies with carbon content. On the version of the instrument installed at Hammond, approximately 375 grams of ash are required to perform the analysis. Upon completion of an analysis cycle, a portion (less than 25%) of the cell is purged to allow a similar amount of newly collected ash to enter the system. In this way, the system displays percent unburned carbon as a rolling average. The ash ejected from the measurement cell is transported back to the flue gas stream using the outlet flow from the exhauster. The total cycle time varies with ash loading. Cycle times of 30 minutes (full load) to greater than two hours (low loads) are typical depending on ash loading. The instrument is controlled by an internal PLC which also provides 4-20 ma or voltage signals to a DCS or other recording device.

Table 1 provides information extracted from SEKAM literature and provided by the manufacturer.

Figure 1
SEKAM Monitor Probes

Figure 2
SEKAM Monitor (Front and Interior View)

Figure 3
SEKAM Measurement Chamber

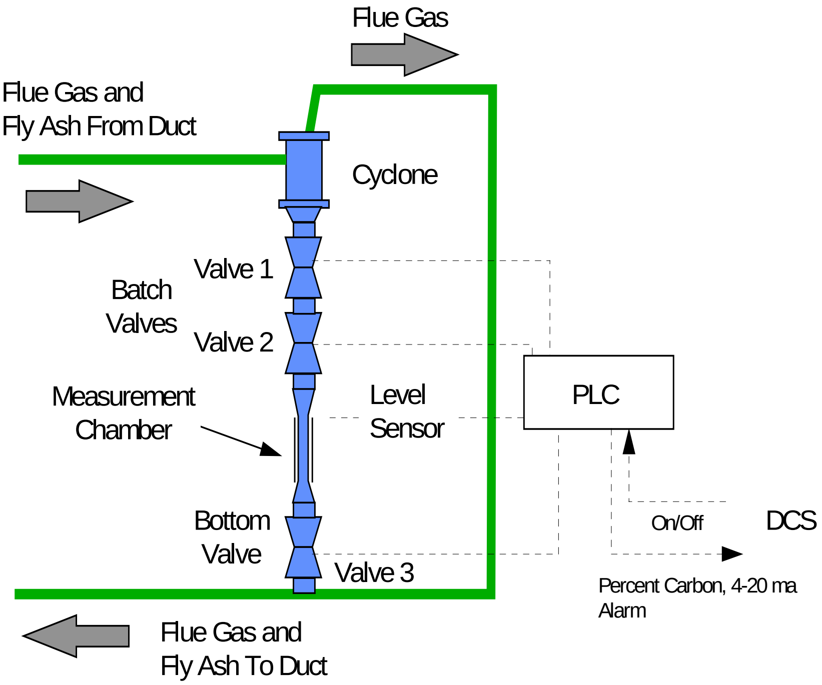

Figure 4
SEKAM General Arrangement

Table 1
SEKAM General Information

SEKAM Carbon-in-Ash-Monitor	
Operating Principle	Capacitance
Instrument Size (W x D x H)	5.3 ft x 1.3 ft x 7.2 ft (1.6m x 0.4m x 2.2m)
Instrument Weight	800 kg / 1760 lb
Power Requirements	110 VAC / 20 amps
Instrument Air	80 – 100 psi / 2 scfm
Plant Air	80 – 100 psi / 70 scfm
Ambient	14°F to 122°F, 10% to 95% RH
Mobility	instrumentation: low sampling device: low
Sample Size	~375 grams
Quoted range	0 – 30%
Quoted Accuracy	± 1.2% (0 to 15% carbon content)
Analysis Display	% carbon or LOI
Response Time	~ 15 minutes
Normal Maintenance	• Replace seals six months
Cost	$45,000 - $50,000 depending on options
Contact	Robert Jones Clyde Pneumatic Conveying Shaw Lane Industrial Estate Doncaster South Yorkshire DN24SE UK +44 1302 321313 phone +44 1302 369055 fax

Installation

The SEKAM on-line carbon-in-ash monitor was installed at Plant Hammond Unit 4 during fourth quarter 1994. This system sampled from two locations at the economizer outlet. Only two probes were installed because existing ports were utilized and there was hesitancy to install even more ports on a duct that was already extensively instrumented. This system was delivered to the site on October 5, 1994 and installation was completed on December 14, 1994. Major activities associated with the installation of this system included:

- Placement of control unit in boiler building (Figure 5). The floor area required is 1600 mm (5.3 ft) x 400 mm (1.3 ft) with overhead space of 2200 mm (7.2 ft). Floor loading is approximately 800 kg (1760 lb). The control unit is located at the rear of the furnace at elevation 684 feet.

- Installation of two sample lines and sample return line. The sample lines were insulated and heat traced to maintain the temperature of the extracted ash/gas stream above 80°C (176°F). The sample lines extract gas from the flue gas stream at the economizer outlet near elevation 653 feet. The return line enters the flue gas stream near the extraction points at the economizer outlet.

- Routing of power wiring. The control cabinet required 110 VAC at 30 amps and provides power for both cabinet electronics and heat tracing. No other power was required.

- Routing of instrument and plant air. Plant air, at 100 psi and 94 scfm, is required for the exhauster. A filter was installed to clean the plant air prior to use in the SEKAM. Instrument air, at 87 psi and 10 scfm, is used for control purposes (air operated valves). Two filters (in series) were installed to clean the instrument air prior to use in the SEKAM.

- Addition of input/output points to the digital control system. Outputs from the SEKAM connected as inputs to the DCS include: (1) a 4-20 ma signal representing carbon-in-ash and (2) a contact representing a fault signal. Provision was also made so that the unit could be activated and deactivated through the DCS whenever the economizer outlet temperature falls below 400°F or when no mills are in service. This precaution helps prevent moisture condensation and potential plugging of the extraction and return lines by fly ash. The signal wires between the SEKAM and the DCS are terminated at the remote termination unit of the DCS located at elevation 662 feet on the west wall of the furnace.

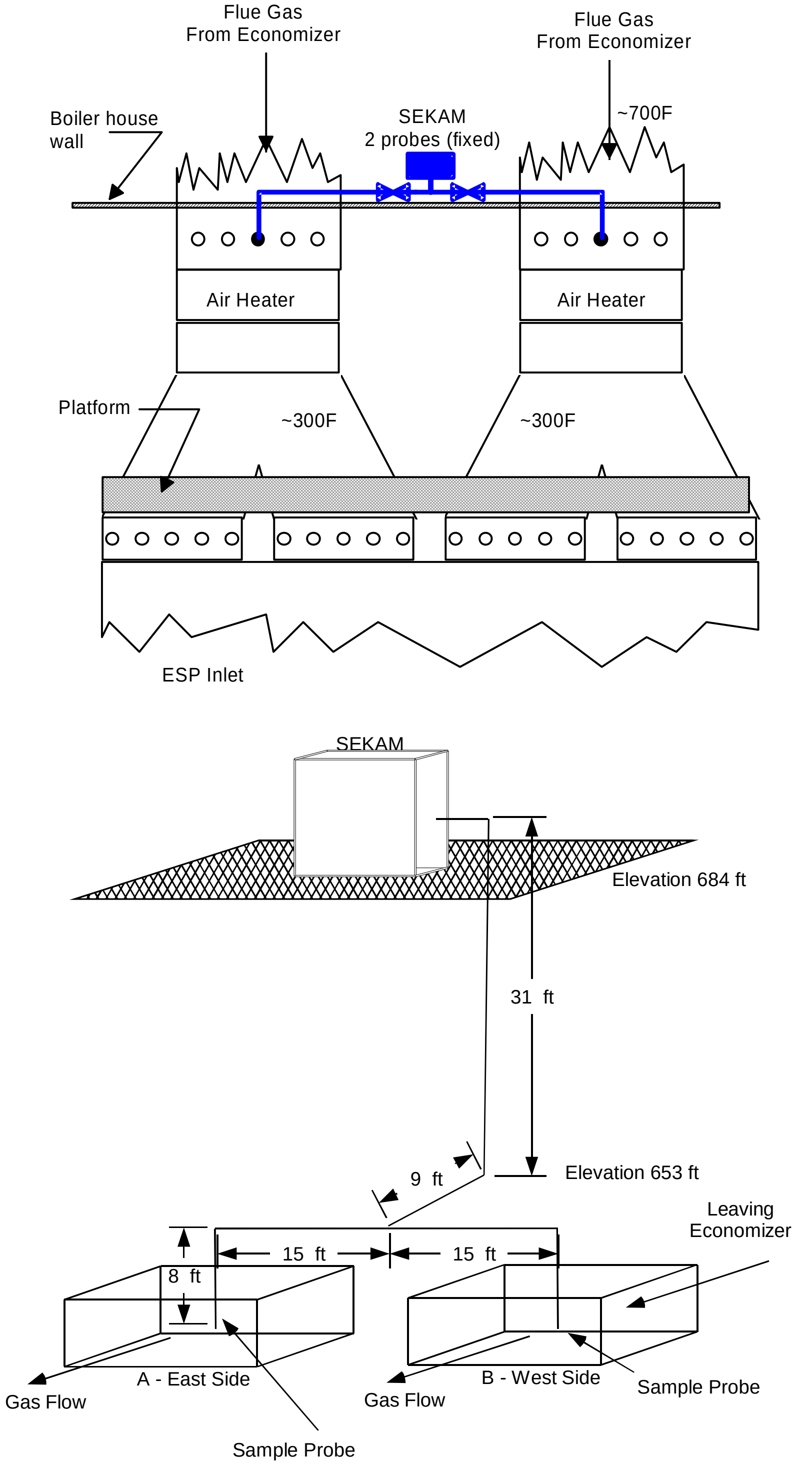

Figure 5
Installation of SEKAM at Hammond 4

Comparison of SEKAM to Manually Collected Samples

The first round of testing of this instrument was conducted July 20 and 21, 1995 at Hammond. 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 (300, 400, and 500 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 approximately 70% of the fly ash collected by the precipitator. Since the SEKAM provides a composite reading representing the "A" and "B" sides, the results of the lab analyzed samples were averaged.

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 isokinetic samples collected manually is shown in Figure 6. 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 oxygen 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. The accuracy limits provided by the manufacturer are also shown in this figure. As shown, the SEKAM LOI trended fairly with the LOI of the isokinetically samples, however, there was a consistent offset in the readings. This error could be caused by numerous factors including:

- Sampling error – The SEKAM samples from only 2 sample points and the collected ash may not be representative of the overall ash characteristics.

- Time response of the instrument – Because of relatively long sampling periods of this instrument, the SEKAM may not have reached a steady-state condition prior to starting another test.

- Improper calibration – Although the instrument was initially calibrated using Hammond ash samples, there may have been some variation in the coal supply between calibration and these tests. Although this may have been a factor, Clyde does not specifically recommend re-calibration of the instrument with a change in the coal.

- Errors in the Isokinetic Method – Although generally considered the most robust method, multi-point isokinetic sampling with subsequent lab analysis is also susceptible to measurement errors including those associated with sampling error and lab analysis of the collected sample.

A comparison of the same SEKAM results to a composite hopper sample yields similar results (Figure 7). The hopper sample value is a simple average of the eight individual hopper ash LOI values obtained for each test.

A second round of testing of the instrument was conducted February 8 and 9, 1996. The scope of the testing was similar to that conducted during July 1995 with isokinetic and hopper samples being collected. During part of these tests, the SEKAM unit was unavailable for operation because of a mechanical failure in the instrument. As shown in Figure 8, for the tests conducted, SEKAM provided a fairly good estimate to the LOI of the isokinetic samples. However, given the relatively small range of LOI samples for the test the SEKAM was available, a trend could not be determined. A comparison of the SEKAM to the hopper values is shown in Figure 9. For this particular test sequence, the instrument values more accurately matched the LOI obtained form the hopper values than that of the isokinetically collected samples.

Inherent Accuracy

Accuracy of the SEKAM instrument was further evaluated by placing ash samples with known LOI directly into the evaluation cell for analysis. An advantage of this procedure is the removal of concerns about collecting representative samples to compare with duct composites. In addition, it presented an opportunity to select ash sources which would intentionally provide a larger range of LOI values over which to evaluate accuracies. Possible explanations for the differences in instrument and lab LOI include moisture which could have been absorbed by the ash samples from the atmosphere during storage prior to use with the instruments. With the SEKAM analyzer, it is expected that moisture would result in a higher reading. As shown in Figure 10, the SEKAM readings showed the same general trend as the lab readings; however, sensitivity of the SEKAM was much reduced over that observed during the isokinetic comparison. Results shown in this figure are from ash collected at sites other than Hammond.

Time Response

When used for control and optimization, timeliness of the response is an important consideration. The response for the SEKAM is shown in Figure 11 for February 9, 1996 during which the unit load and excess oxygen varied. As shown, the total response time of the SEKAM to these changes was approximately 1½ hours. For greater loads, the response time is reduced whereas for lower loads, the response time is extended. The SEKAM also periodically experienced leaks in the sample lines that would extend the sample time and this may have also contributed to the long sample collection time. Full-load ash loading on Hammond 4 is approximately 0.09 grams/sec-cm^2.

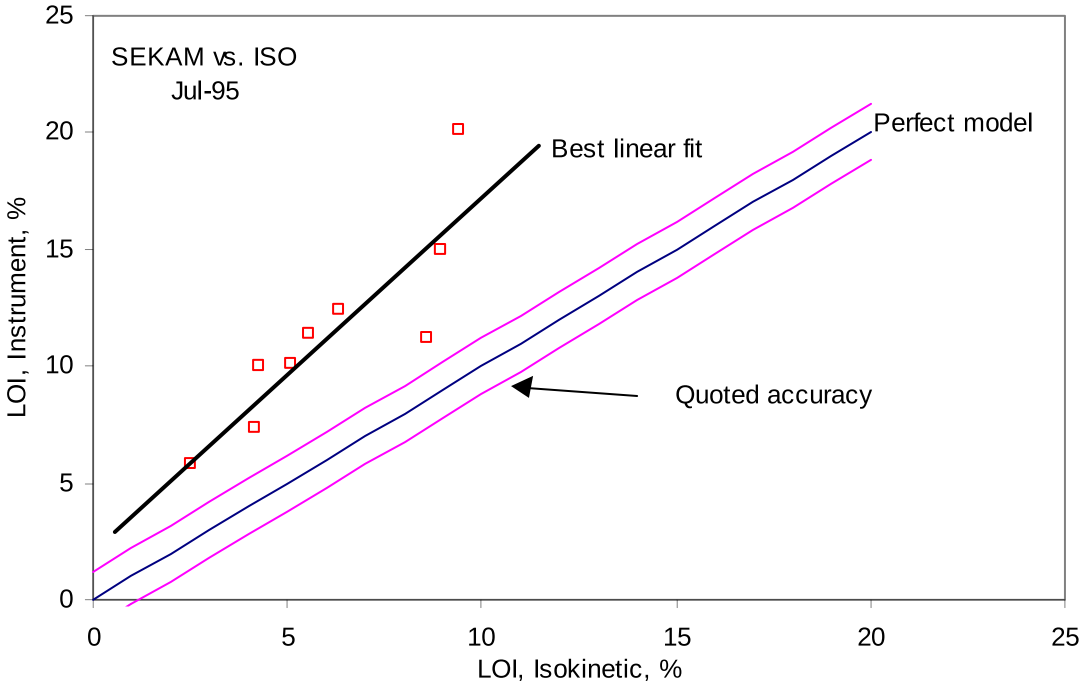

Figure 6
SEKAM vs. Isokinetic Samples – July 1995

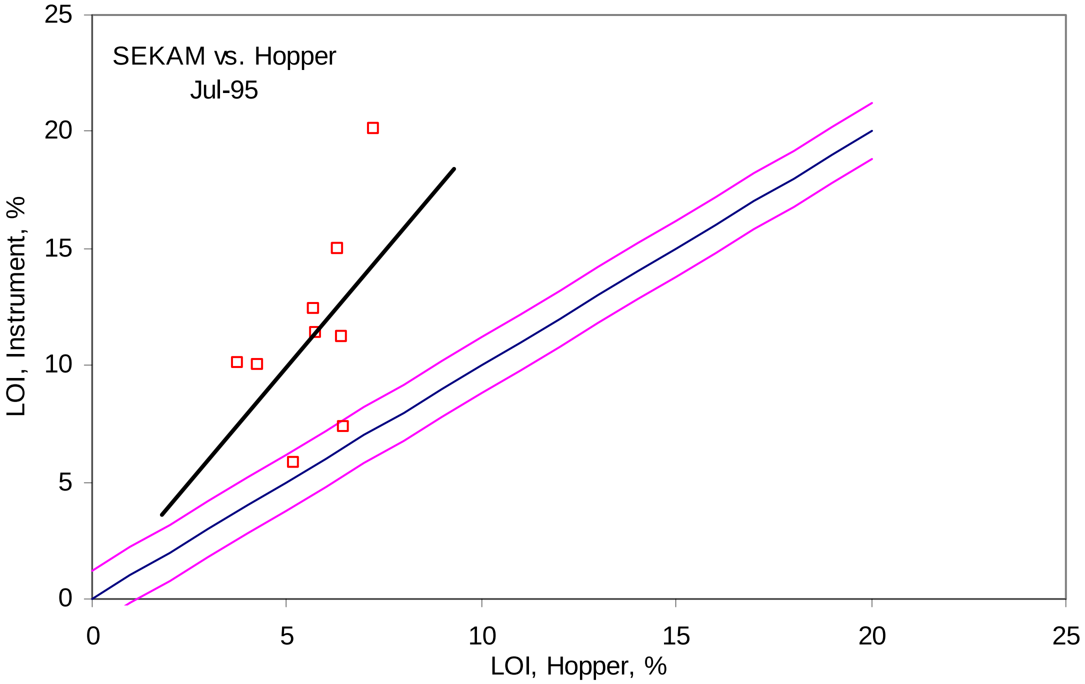

Figure 7
SEKAM vs. Hopper Samples – July 1995

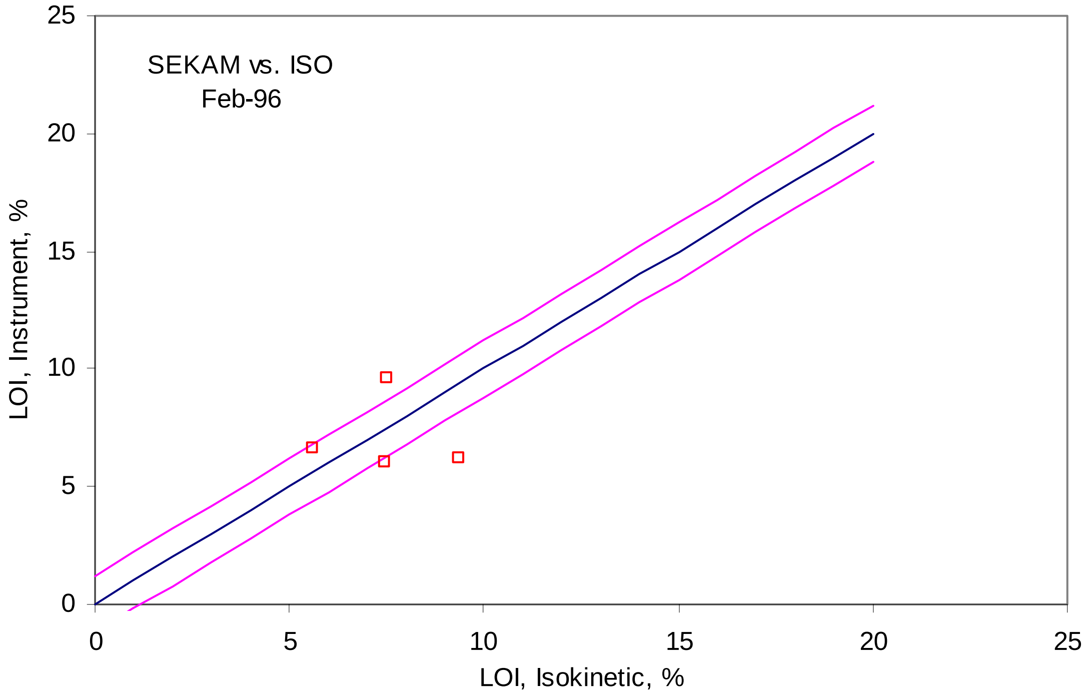

Figure 8
SEKAM vs. Isokinetic Samples – February 1996

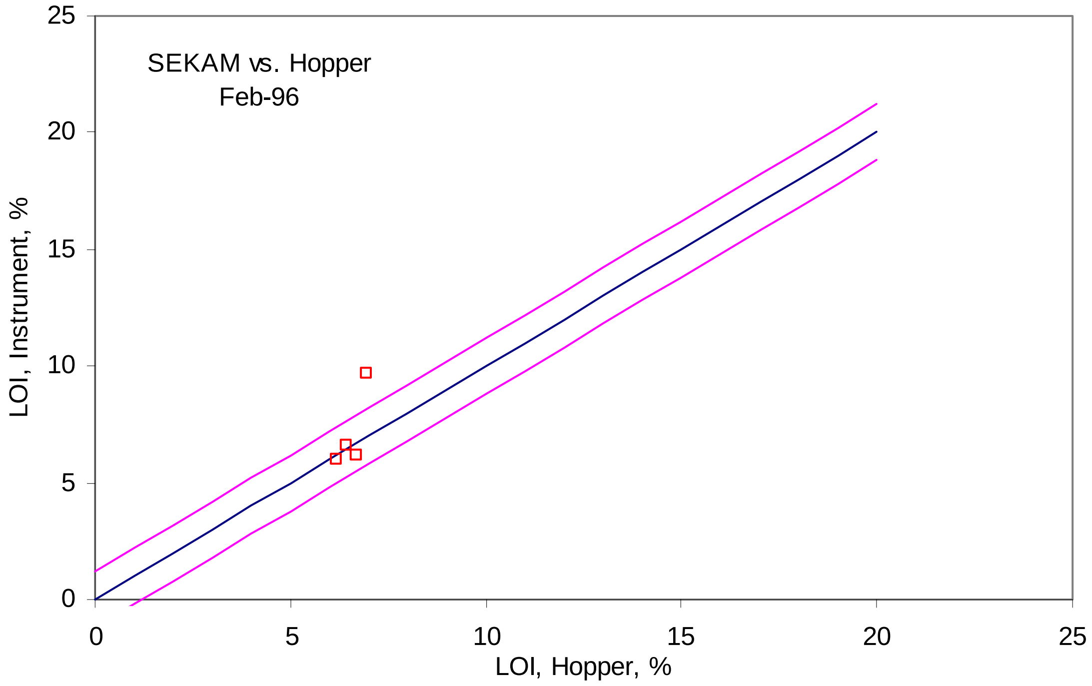

Figure 9
SEKAM vs. Hopper Samples – February 1996

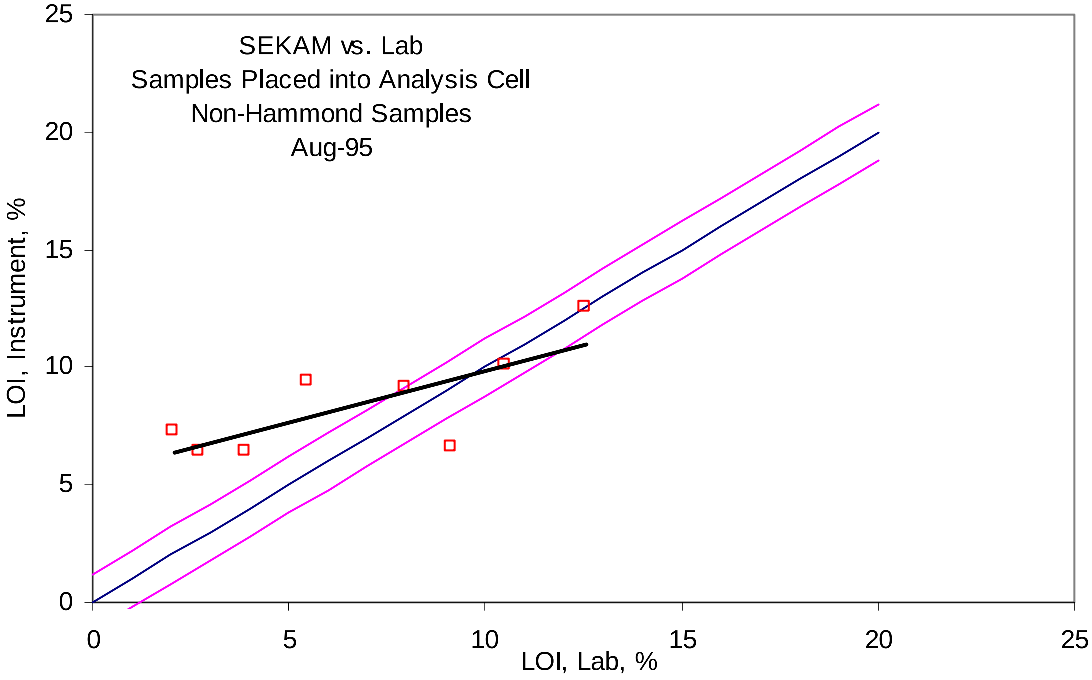

Figure 10
SEKAM Inherent Accuracy

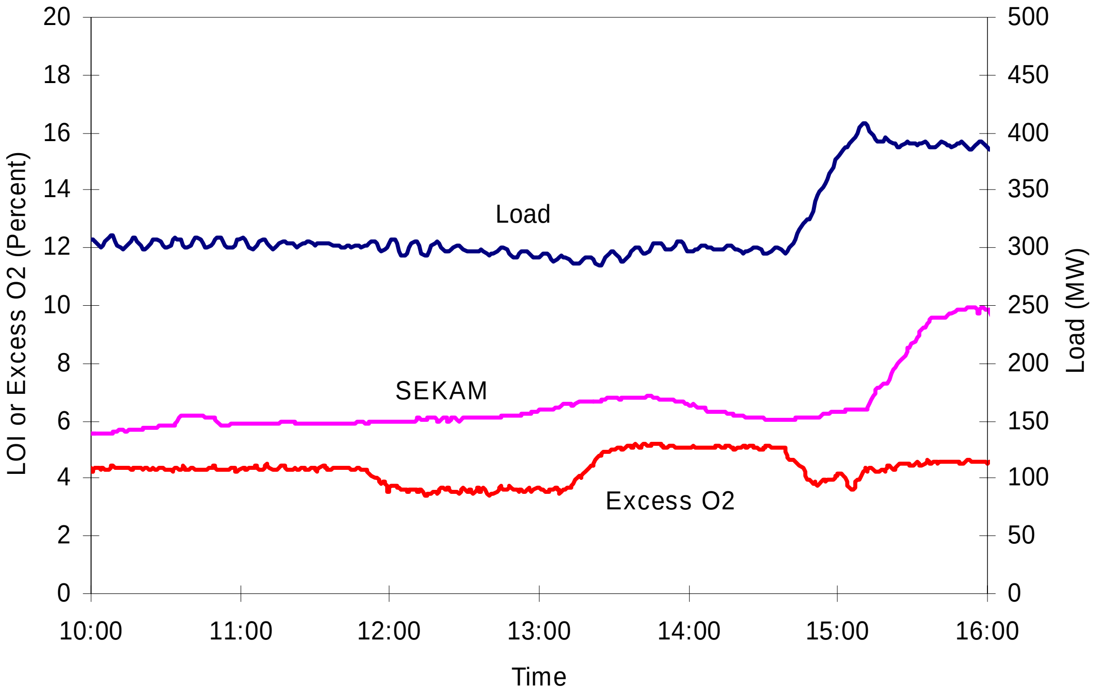

Figure 11
SEKAM Time Response

Reliability and Maintenance Aspects

Since its installation in November 1994, the SEKAM has had a relatively high availability when compared to the other extractive systems tested. Some of the problems that have been encountered and the remedial action were:

- Unit not providing readings; A/D converter card replaced.
- Sample valve cycled on and off; valve replaced.
- Extremely low LOI readings; instrument calibrated.
- Small leak in sample cell; valve seals replaced.
- Samples not collected; small holes in sample line patched.
- During early 1997, the sample lines were replaced because of fly ash abrasion.

Also, another major maintenance consideration of this instrument is that there is currently (September 1997) no U.S. technical support or spare parts inventory. All support is now provided out of Clyde's offices in the U.K.