Real-Time Monitoring of Unburned Carbon on Utility Fly Ash

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ABSTRACT

This paper discusses the application of on-line LOI (or carbon-in-ash) analyzers to utility boilers for the purpose of optimizing firing system and thermal performance while maximizing the revenue from fly ash sales. Fly ash value is strongly affected by the unburned carbon content. Fly ash sample collection philosophy and unburned carbon measurement technology will be briefly reviewed. Several installations from around the world using a multiple sampling point, microwave based system will be described and improvements to plant operation discussed. Special emphasis will be placed on commercial installations and use of the technology in the United States. The installations cover a variety of boiler and firing system designs as well as a range of fuel characteristics.

INTRODUCTION

Coal fired boilers have various sources of thermal energy loss. The main sources are the dry gas loss as well as the loss-on-ignition (LOI) of the ash leaving the boiler. The vast majority of the combustible portion of the ash that accounts for the energy loss is simply unburned carbon. The operating approach in the past has been to keep the carbon as low as possible to minimize the combustible losses in the ash. However, the most efficient way to operate a boiler is to minimize the energy losses due to the fly ash LOI and the stack gases at the same time. In addition, the disposition of the fly ash plays an ever more important role in the overall economics of the power station. More power stations are selling their fly ash rather than pay to dispose of it. This gives the facility a new revenue stream and, at the same time, a reduction in expenses. The result is lower full cycle generation cost. Since the unburned carbon is a highly variable parameter which is dependent not only upon coal type but also upon load, fuel and air distribution, and other boiler-specific factors, the need for on-line measurement has become more critical. Fly ash becomes an even more attractive product if it is of consistent quality. In many cases, providing a fly ash of consistent quality is more important than maintaining a very low carbon or LOI content. Producing a consistent fly ash stream requires modern controls which rely on accurate and reliable UBC measurement on a near real-time basis.

Ash Sampling

The most important features of any fly ash measurement system involve the approach to ash sampling and the subsequent analysis of that sample. Samples analyzed must be representative of the vast majority of ash leaving the boiler or the information generated will be misleading. In many on-line applications in the past, the measurement system draws ash samples from a very large flue gas duct. This approach only allows the coverage of a small percentage of the cross sectional area (typically only a fraction of a square inch). Therefore, the coverage of the cross sectional area is minimal resulting in a non-representative sample of the ash flowing through the duct.

Figure 1 illustrates data collected and reported by GAI Consultants from three large flue gas ducts on a nominal 860 MWe, coal-fired utility boiler. The boiler is a supercritical, tangentially-fired unit with an LNCFS Level III low NOx firing system. It is a twin furnace design with three economizer ducts reporting to three air heaters. The data was collected in the down flow section of ductwork between the economizers and the air preheaters. A multi-point sampling grid was installed and isokinetic samples were collected over a wide range of operating conditions. This one data set is typical of numerous sets collected at various loads and boiler firing conditions and is simply included here to illustrate the maldistribution of fly ash as it flows with the flue gas exiting the boiler. There is simultaneous variation of both mass flow and unburned carbon composition of the ash. Even at constant load and firing conditions, the distribution changes due to fuel composition variations and changing furnace and convection pass cleanliness. Even larger variations occur as load changes and firing system adjustments are made.

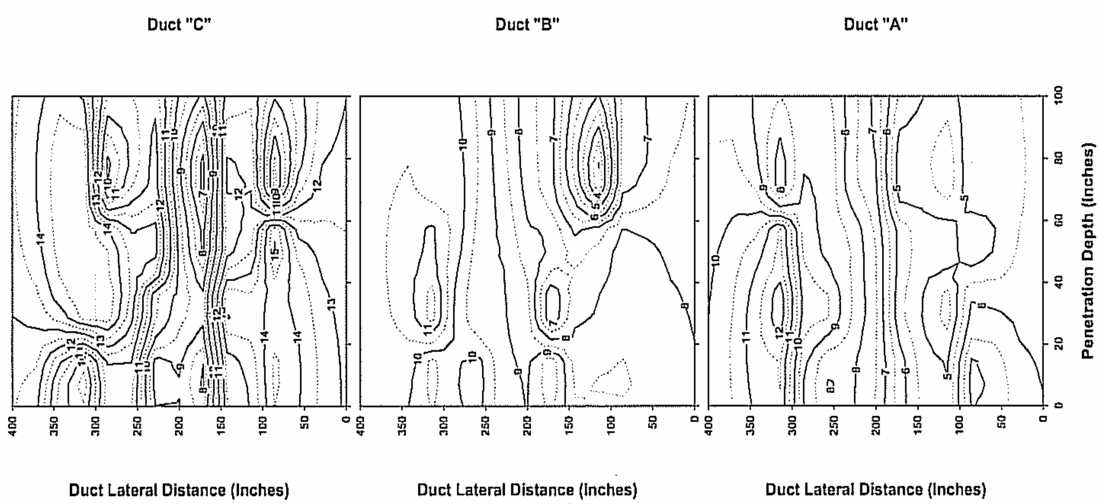


Figure 1: Typical fly ash LOI maldistribution in boiler flue gas ducts

It is clearly impossible to locate any ash sampling system, short of a complete duct array of sampling devices, which will collect a representative ash sample for all boiler operating conditions. This is simply not practical from either an economic or a plant operating and maintenance perspective.

A more practical approach is to collect samples at a location where the vast majority of the ash has already been collected - namely the first collection field of the electrostatic precipitator or fabric filter. This location has been selected by many European power stations as being most representative when compared to the ash finally delivered to the ash storage silo. Collecting samples exactly at this location provides the power station with two major advantages:

a) The measurement is representative of the ash being produced.
b) The values measured can be compared with laboratory measurements made on the identical sample, which leaves little room for "interpreting" the accuracy of the instrument measurement.

Figure 2 is a graphical illustration of the two sampling approaches in a typical power station. The conventional flue gas sampling approach is able to address only a minute amount of the fly ash while the bulk sampling approach addresses a much larger proportion. Although the composition of the ash will indeed vary in the second, third, and additional precipitator collection fields, the quantity is such that there is typically only a small difference in the composition of a mass weighted composite sample from all the fields compared to the composition of the first field alone. If that is a concern, additional sampling locations can be selected from a larger number of hoppers. A single instrument can report UBC content from 8 different sampling locations.

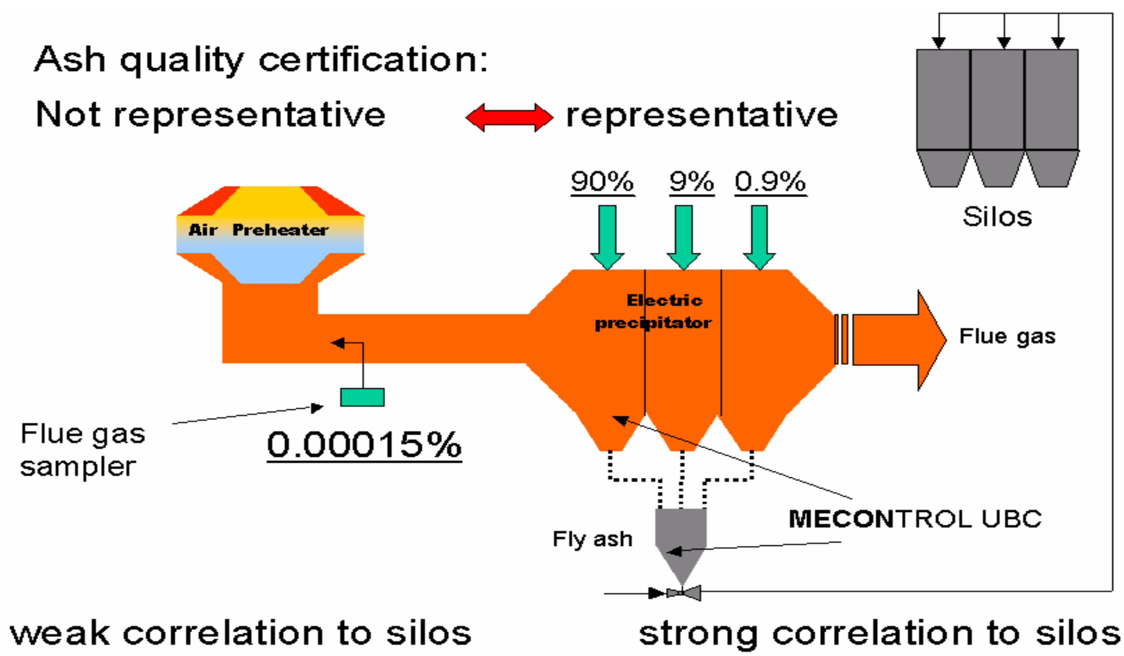
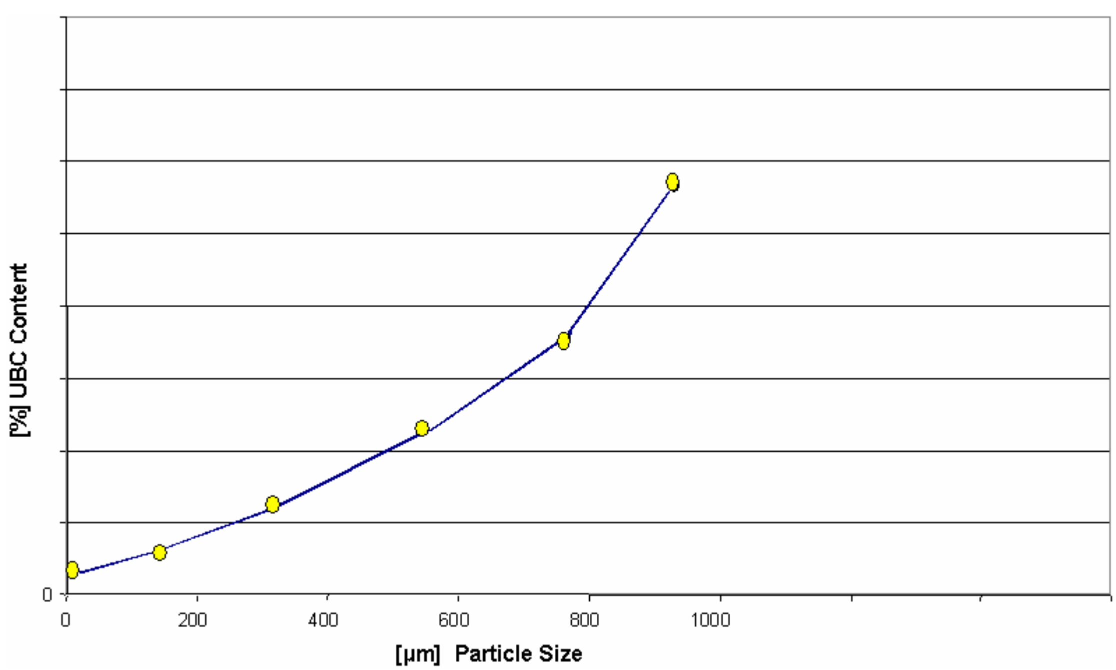


Figure 2: Comparison of sampling locations

It is interesting to note that the European experience has guided utility customers away from a concern for the measurement accuracy of the instrument itself. They are now interested in the "system" accuracy as applied in the field and how data reported compares to laboratory analysis of the ash that eventually ends up in the storage silos for subsequent sale or disposal. The real-time values delivered by any UBC system should correlate well with the values produced by a laboratory measurement of the same sample. For this reason, only technologies that are able to provide a laboratory sample from the instrument itself are considered. Any optical or other technology approaches that do not provide an ash sample for direct comparison with laboratory analysis are no longer considered acceptable practice by German utilities.

Another aspect of accuracy with this approach is the fact that the amount of fly ash sample is large enough and is sampled without an extractive method. The reason for this is the fact that the separation of the fly ash from the flue gas stream, usually accomplished with a small cyclone separator, causes significant segregation in particle size of the fly ash sample actually analyzed. Figure 3 illustrates that UBC content in fly ash is a strong function of the particle size.



Data courtesy of E-ON Engineering, Germany

Figure 3: Fly ash UBC as a function of particle size

Field tests have shown that any sort of pneumatic separation of the ash sample from the gas stream by a cyclone will result in deviations between laboratory and measurement instrument analyses. The magnitudes of the deviations vary depending on the coal type, combustion conditions, and other site-specific factors. As those factors vary, the amount of fine carbon particle versus large carbon particles produced also varies. Any UBC instrument sensitivity to coal type is in large part a problem of sample extraction and solids separation within the instrument sample handling system itself. A screw sampler avoids this problem which helps minimize any impact of changing fuels and/or combustion conditions.

Mechanical Reliability

The amount of sample handling during the collection and measurement by a UBC instrument also impacts the instrument reliability. Figure 4 is a schematic comparison of the sample handling involved with conventional extractive measurement systems and in situ systems. The left hand side illustrates a typical extractive system. Its critical steps of measurement are:

- heating of the pipes (clogging and congestion of pipes)
- moving parts (valve seats, actuators etc, cyclone operation)
- mechanical accuracies (weighing)
- mechanical wear (high ash velocities accelerated by purge and transport air)

Minimizing mechanical functions is the key to reduced maintenance and high instrument reliability. It is not the selection of high quality valves and materials, but the simplification of the handling process that makes a system reliable.

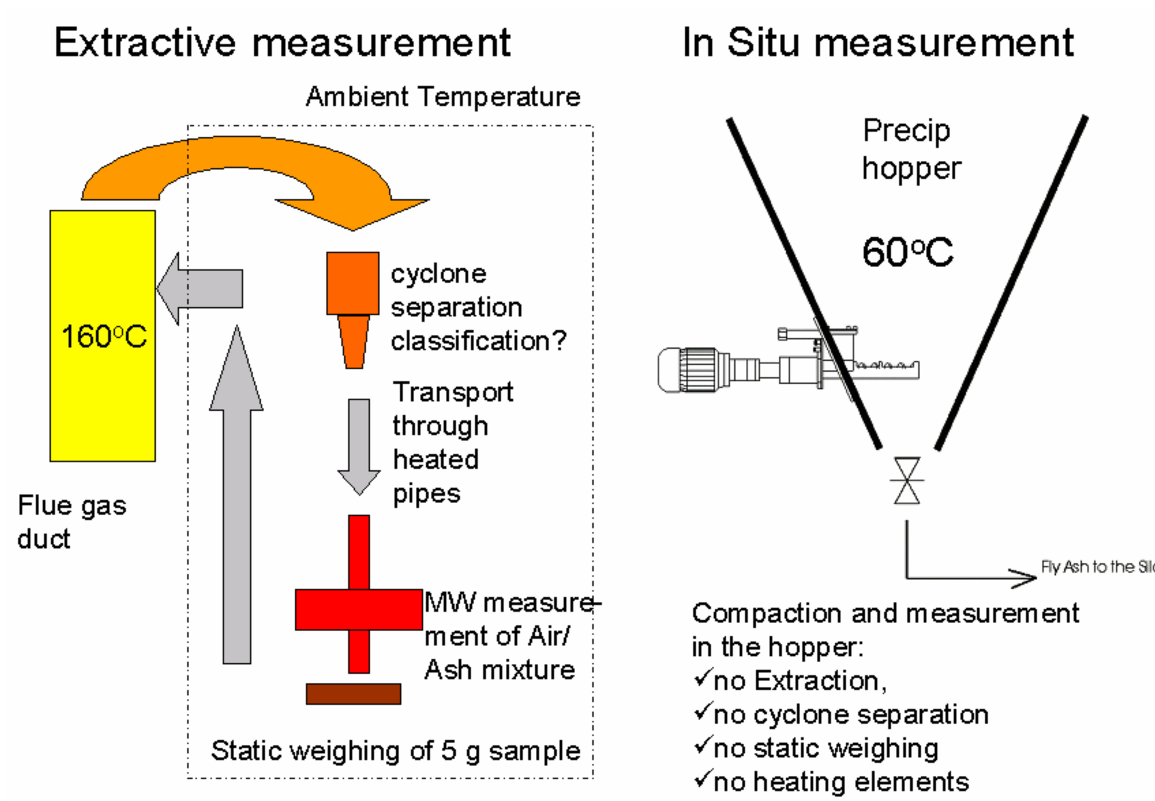


Figure 4: Schematic comparison of sample handling

The mechanical reliability is absolutely critical to the operation of the system in a power station environment. Many UBC measurement systems that have been replaced over the past few years had been out-of-service for some time because the power station could not afford to maintain them. They simply could not afford the resources to do the things necessary to keep the instrument functioning, including:

- weekly inspection of valves
- weekly inspection of mechanical parts such as load cells (weighing)
- parts replacement due to erosion
- frequent adjustment due to leakage at tubing connections
- frequent cleaning of blocked components
- difficulty in obtaining samples for laboratory analysis

These issues can be avoided by relocating the handling functions and the measurement sensor into the ash (in situ) rather than trying to bring the ash into the measurement system (extractive).

Unburned Carbon Measurement

There are several technologies widely used to measure the actual unburned carbon content of a fly ash sample. The most common are:

a) Reflectance: This method utilizes the fact that fly ash with different UBC content has a different color. Characteristics of reflected light are used to measure the amount of unburned carbon. This method has not been very successful because it is extremely sensitive to coal type. This means that for each coal burned, a unique correlation between measured results and laboratory results needs to be established.

b) Combustion: This method imitates the laboratory method of burning the sample and measuring the weight loss for LOI content or the CO2 emission from the combusted sample for UBC content. This method has the main disadvantage of being rather complicated. The instrument must accomplish many individual steps of analysis which requires a significant amount of automation hardware. This results in significant maintenance requirements which most power stations simply cannot support in today's competitive environment.

c) Microwave: This is a very simple and reliable method. It is based on the fact that the unburned carbon and the fly ash have much different responses when subjected to microwave radiation. This fundamental difference in physical properties is utilized to measure the change in resonance frequency of a resonating device. This change in resonance frequency is nearly linear with the change in unburned carbon content of the fly ash. There are several systems on the market which use this measurement principle. The only issue is to get the ash into the sensor/resonance chamber. This problem can be resolved by moving the resonator close to the ash. Ash is not extracted from the plant ash handling system and is therefore unaffected by external equipment.

COMMERCIAL UTILITY APPLICATIONS

European Power Station

The first system using this method was installed in 1999 in a power station belonging to the German utility E-ON. The system was applied in Scholven Power Station, a 3600 MW coal fired power station. The system underwent various tests including an extensive assessment of accuracy using a wide range of international coals. Other acceptance criteria included availability as well as reliability and maintenance requirements. Since that first installation, PROMECON, GmbH has become the exclusive supplier for UBC systems to E-ON for all their German power plants. In total, UBC systems for more than 40 boilers with a total of more than 90 sensors have been installed. These systems are currently operating in Germany, Holland, Austria, Spain, Japan, China and the United States. A typical utility boiler application is shown in Figure 5.

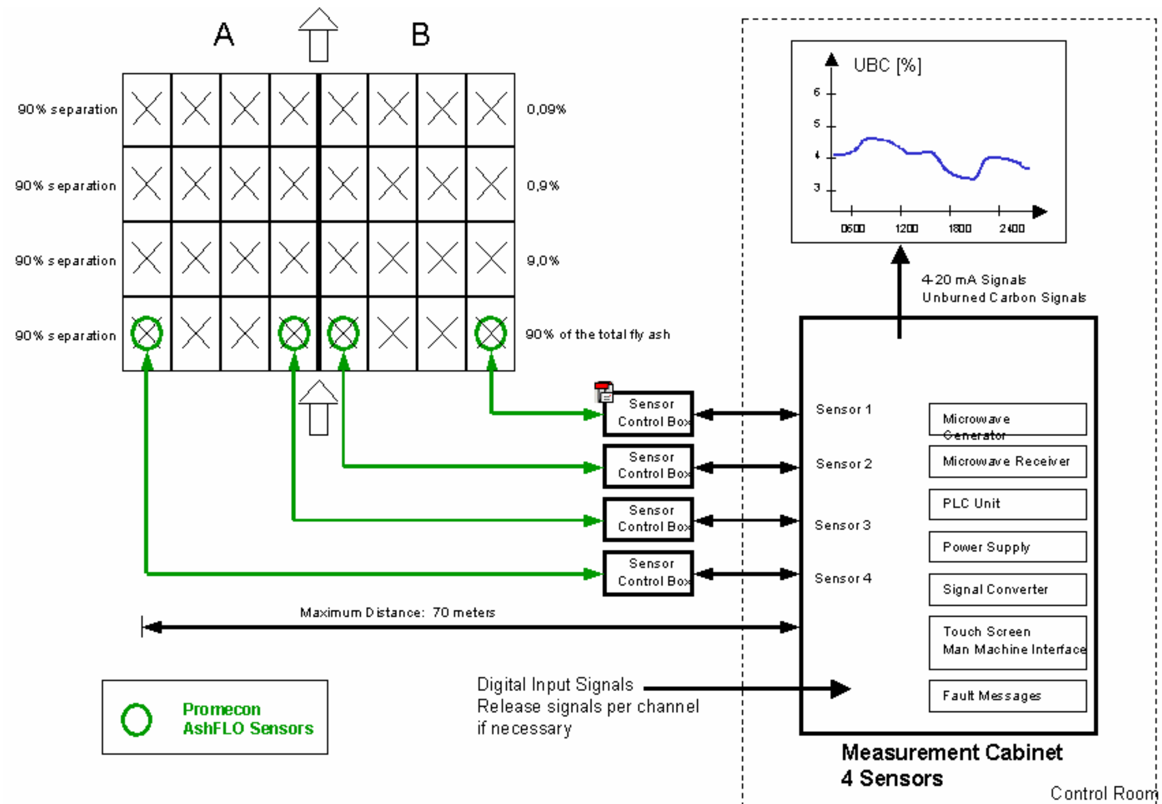


Figure 5: Typical utility boiler UBC system application

In this case, flue gas flows through two parallel ducts into the electrostatic precipitator. UBC sensors were installed in four of the first field ash hoppers which the utility had determined provided a very representative portion of the boiler fly ash. A local control panel is mounted near each sensor and power and communication cables run from each control panel to the main control cabinet. The main control cabinet is usually located in a fairly clean environment and can be up to 300' from the sensors. A 4-20 ma signal, proportional to unburned carbon content, is generated in the main cabinet for each sensor and communicated to the plant control system. A telephone modem is also provided for remote communications with the system for monitoring it's operation and for diagnostic and maintenance services.

Typical delivery of a system as described is 6-8 weeks and system installation can normally be accomplished in less than two weeks. On balanced draft units, the hopper wall penetrations and mounting flange installation can be made with the unit on-line. Pressurized units normally require a short outage for the hopper work to be performed. The balance of the installation involves conduit and cable installation and electrical terminations.

Midwestern US Power Station

The first example is a typical Midwestern US power station firing Eastern Bituminous coal. The station is equipped with 2 down-fired pulverized coal boilers built by Babcock & Wilcox and installed in 1952/53. The units are single reheat design firing various eastern bituminous coals. They have both been retrofitted with low NOx burner systems.

From plant start-up until the present time, fly ash was disposed on-site, at various land fills, and in mine reclamation work. Throughout the history of the plant, ash sales have played an important part in reducing the cost of generating electricity. Ash sales diminished with the installation of Low NOx burners. Low NOx burners historically raise LOI levels in fly ash and make it more difficult to market. LOI levels at this station typically range from 5 % to 7%. The variability of the ash quality also made it more difficult to market. The plant ash removal system was upgraded in 1986 from an air slide system to a vacuum system.

This plant, like many power generation facilities today, strives to find alternate uses for the fly ash that it generates. Over the years, fly ash has been used in many local construction projects. Station management decided in 2002 to install a system to provide fly ash UBC analyses from 2 boilers as well as from the plant fly ash truck loading facility. The system was intended to help increase ash sales by providing boiler operators with a real time display of their fly ash quality and also to provide the local fly ash broker with ash quality data while loading trucks.

Two sensors were installed in the first field ESP hoppers on both units #1 and #2. In addition, one sensor was installed near the outlet of each of three fly ash storage silos. A local control box was provided for each sensor location and the entire system was wired to a single main control cabinet. Due to the age of the existing control systems, a desktop computer-based data acquisition system with operator interface was also supplied for the boiler control room.

Figure 6 shows the comparison of the UBC results compared to the LOI measurements of the plant laboratory. Samples were obtained directly from the instrument measurement chamber soon after the unburned carbon measurement was made. The samples (typically 40-50 grams) were split and one part of each sample was analyzed by the plant analytical laboratory. The other part was analyzed by a commercial laboratory often used for calibration data. The agreement between the two was very good. All of the reported data is from the station laboratory. Each UBC sensor is reported as a "Channel" by the control cabinet software. The deviations measured were as follows:

Standard deviations to Laboratory results (1 sigma):

Channel 0: 0.17%	Channel 4: 0.10%
Channel 1: 0.15%	Channel 5: 0.16%
Channel 2: 0.28%	Channel 6: 0.25%
Channel 3: 0.15%	

All Channels: Std. deviation (80 samples) = 0.18%

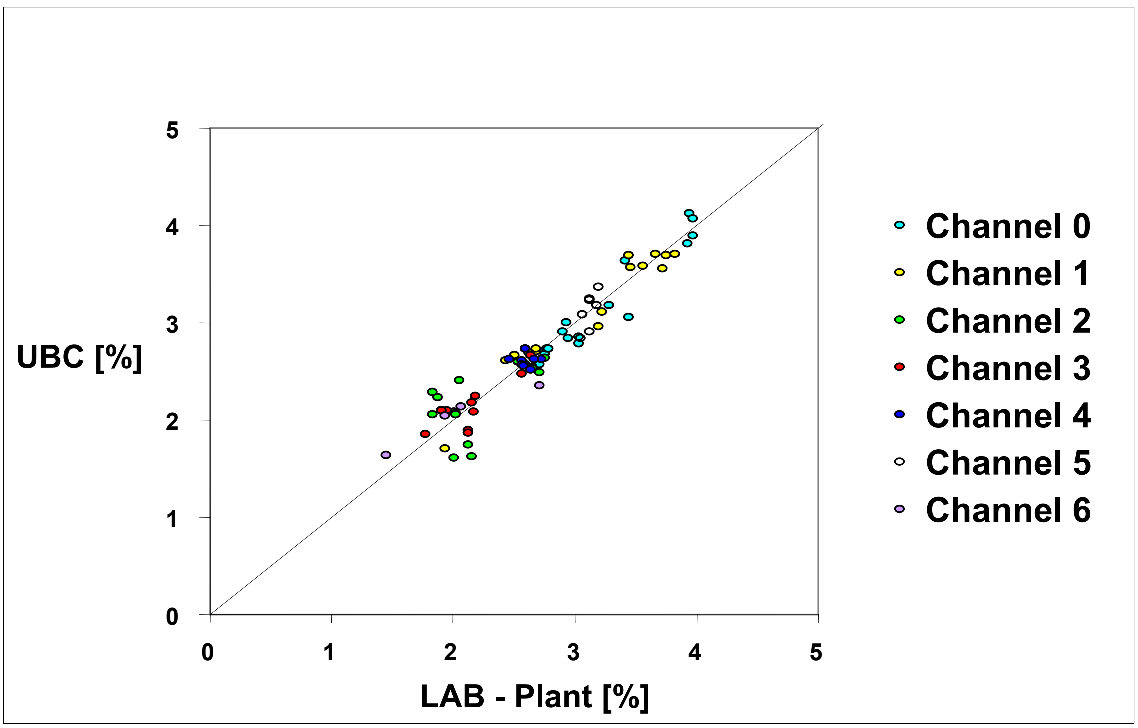


Figure 6: Comparison with laboratory results

The system has been running since the commissioning virtually maintenance free. The sensor screw packing gland material was checked and replaced on four of the

sensors after approximately six months of operation. No other maintenance has been performed.
Figure 7 shows instrument output over a much longer period of time. Two first field ESP hopper results are shown for a period of approximately four months. The short periods during which data is absent are due to unit outages.

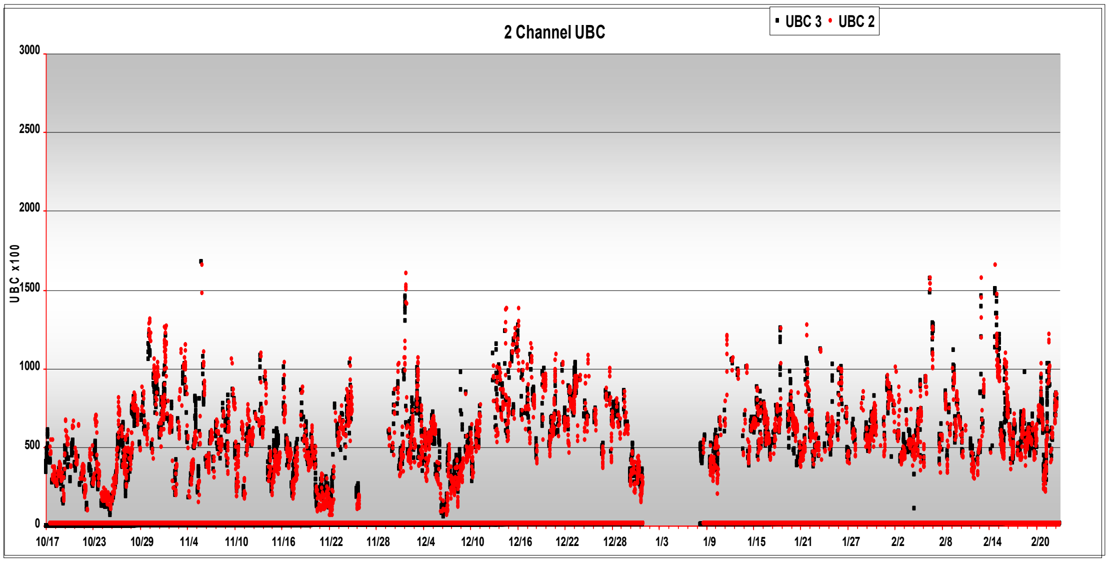


Figure 7 Long Term UBC Data Trends

Since the system has been installed, plant ash sales have increased from 300 tons/month (1st quarter, 2003) to 2000 tons/month (3rd quarter, 2003). This is a direct result of having nearly real-time UBC information available to the operators and combustion engineers so that they can make appropriate adjustments to excess air levels, burner registers, etc. to assure the production of saleable ash. Ash sales have continued to increase throughout 2004 with cumulative benefits (ash sales revenue and reduced landfill cost) exceeding $200,000 for the first seven months of the year.

Firing system and combustion air flow adjustments can be better optimized now that operators get information on the UBC impacts much faster. The fly ash quality has become much more consistent which has improved relationships with ash vendors and customers. In addition, operators no longer have to collect ash samples manually during each shift. Instrument output is available at the main control panel touch screen interface, on the control room SCADA system, or can be accessed via modem from any telephone. PROMECON technical staff routinely checks the system operation and can remotely diagnose problems, as well as update software and calibration information without travelling to the plant. PROMECON also offers monitoring and maintenance agreements which eliminate virtually all plant maintenance requirements and assure very high availability of the system.

ADDITIONAL BENEFITS

In addition to the benefits documented at these two installation, others have been identified from numerous facilities using on-line unburned carbon analysis systems worldwide. These include:

1) Increased boiler efficiency
2) Reduced UBC content
3) Reduced CO emissions
4) Reduced NOx emissions
5) Reduced SNCR/SCR ammonia consumption
6) Increased ash disposal site life
7) Increased SCR catalyst life
8) Reduced auxiliary power consumption
9) Reduced water wall slagging and corrosion
10) Reduced electricity generating cost

Each of these benefits or some combination thereof, has been identified at other power stations that have retrofit on-line unburned carbon monitoring. The actual benefits achieved at each installation vary depending on the firing equipment, generating requirements, emissions constraints, ash markets, and other plant operating criteria.

SUMMARY

Over the past several decades, a number of technologies have been developed and applied to measure, on a nearly real-time basis, levels of unburned carbon in the fly ash produced by combustion processes. The ability to truly optimize a combustion process is strongly dependent on the speed at which operations personnel receive feedback on this fundamental process indicator. The recent integration of microwave measurement technology with a very simple, non-extractive ash sampling/handling mechanism has finally produced a measurement system that is accurate and reliable enough for utility steam generator application. More than 40 such systems have been retrofit to utility boilers worldwide with excellent performance results. Several commercial installation in the United States have been completed on several different boiler and firing system types. Accurate, repeatable indication of fly ash unburned carbon content has enabled these stations to produce a more consistent ash product which has resulted in increased ash sales, reduced ash disposal costs, and more consistent boiler operation.