On-Line Monitoring of Carbon in Fly Ash for Boiler Control

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ABSTRACT

It is generally agreed that reliable real time measurement of unburnt carbon in fly ash is a valuable tool for boiler monitoring and control in coal burning power stations. It also facilitates more effective utilization of the fly ash, as ash quality may be more effectively controlled. A new design of on-line carbon in fly ash analyzer, the CIFA350, was placed on trial at Tarong power station in late 2006. The trial was successful and all four boilers at Tarong have now been fitted with carbon in fly ash monitors. The CIFA350 uses a non destructive method of analysis to determine the percentage of unburnt carbon in the fly ash. This provides close to real time unburnt carbon data and also allows samples to be collected for laboratory analysis when required. The analyzer has demonstrated good reliability and accuracy with minimal maintenance requirements. In this paper the new design is described and maintenance requirements are discussed. Comparison of the analyzer results with conventional laboratory analyses are presented. The use of real time unburnt carbon data for boiler control is discussed.

THE NEED FOR ON-LINE CARBON MEASUREMENT

It is generally agreed that reliable measurement of unburnt carbon in fly ash is a valuable tool for boiler monitoring and control. (Rowe 1993). A 1993 technology review by EPRI stated that, “by using carbon in ash monitors, utilities can optimise burner performance, lower unit heat rate, diagnose developing problems with pulverizers, dampers and burners, and improve ash utilization” (EPRI 1993).

At Tarong Power Station the specific benefits of on-line carbon in fly ash measurement are seen as;

- An on-line indicator of furnace performance in addition to measurement of excess O2.
- Providing on-line indication of pulveriser/classifier performance with regards to coal fineness and burner performance issues such as slag build up.
- Providing reliable cost effective environmental reporting data in electronic format.
- Assistance with monitoring the effectiveness of coal blends.

In order for carbon in fly ash monitors to be accepted by the industry they must achieve adequate levels of accuracy and reliability. The level of maintenance required is also an issue in power plants. Any device which places high demands on service staff may well be abandoned in favour of more critical service needs.

The challenge for manufacturers is to provide a product with adequate accuracy and reliability, which does not place a significant burden on service staff.

MATERIAL HANDLING PROBLEMS

Currently there is no method of analysing fly ash in the boiler duct, so it is necessary to extract a representative sample of fly ash from the duct for analysis. The CEGRIT sampler (developed by the CEGB in the UK) allows isokinetic sampling of a gas stream from the duct. The fly ash is then separated from the hot gas by a small cyclone. The CEGRIT sampler was originally designed to collect fly ash into a small sample jar for laboratory analysis. However, the CEGRIT can also be used to provide a stream of fly ash to an on-line carbon in fly ash (CIFA) monitor.

Fly ash has a number of characteristics which contribute to materials handling problems. The sample is collected at a high temperature (typically 150 degrees Celsius) and the gas stream in the duct contains significant levels of water vapour and sulfur dioxide. If the fly ash is allowed to cool below the dew point the moisture condenses into a corrosive liquid which can bind the fly ash into a solid cake. Any cool surfaces encountered by the fly ash will be coated by an increasing thickness of caked fly ash, which is hard to dislodge. All parts of the CIFA monitor in contact with fly ash must therefore be kept above the dew point at all times.

Even when adequately heated, fly ash does not necessarily flow freely. Stationary fly ash tends to stick together to form a cake. This means that effective vibration and adequate flows of heated compressed air are required to move the fly ash through the CIFA monitor.

Fly ash frequently contains crystalline silica and can be very abrasive. Components within the CIFA monitor may experience significant wear rates, and these may require frequent replacement. Wear rates may be further increased by attempts to prevent caking and build up, for example by the use of vibrators.

ANALYSIS OF UNBURNT CARBON IN FLY ASH

Unburnt carbon in the fly ash sample is measured by the microwave resonant cavity (MRC) technique (Cutmore 1993, Evans 1992). This was developed in Australia by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in the early 1990s. The patented technology was then licensed to Scantech for commercial production of the CIFA310, Scantech's original carbon in fly ash monitor. The new CIFA350 uses the same measurement principle as the CIFA310, however modern microwave electronics provides better accuracy and stability than was previously achievable.

The microwave resonant cavity is a cylindrical metal cavity with internal dimensions approximately 80mm diameter by 50mm in length. The axis of the cylindrical cavity is vertical, and a sample tube, containing the fly ash, passes along this axis. The sample tube is made of a temperature resistant plastic and has an internal diameter of 8mm. The entire resonant cavity is heated to 130 degrees Celsius to ensure that the sample tube will never cool below the dew point of gases contained within the fly ash.

During sample collection the fly ash slowly fills the sample tube. The tube is vibrated regularly to ensure uniform compaction of the sample. When the tube is full the microwave resonant frequency and resonant Q of the cavity is measured. The presence of the fly ash reduces both the resonant frequency and resonant Q compared with the empty tube values. These values are used to determine the percentage unburnt carbon in the sample. Measurement of both frequency and Q allows a correction for density variation in the compacted fly ash sample.

CONFIGURATION OF THE CIFA350 SYSTEM

The CIFA350 measurement system consists of a measurement module, which handles the fly ash, and a nearby electronics module. A section of duct insulation may need to be removed to allow the measurement module to be aligned with the output of the isokinetic sampling system. The measurement module must be located directly underneath the cyclone so that fly ash can fall down a vertical tube into the measurement module. The electronics module is mounted near the measurement module on the outside of the duct insulation to minimise heat loading.

The fly ash falls vertically down a tube into the CIFA measurement module and into the sample tube. When the required quantity of fly ash has been collected the sample is analysed. The sample tube is then emptied by purging the sample back into the cyclone, and into the duct, by a stream of preheated compressed air. Collection of the next sample then begins. The complete analysis cycle is completed in typically 3 to 5 minutes. At the completion of each cycle a new percent unburnt carbon result is produced.

An optional sampling valve allows the sample of fly ash to be saved into a sample canister rather than purged back into the duct. The sample valve is fitted between the measurement module and the cyclone. Prior to purging the sample valve is automatically moved to the "save" position and the sample is purged into a sample canister rather than into the duct. Saving for a number of analysis cycles allows a composite sample to be saved. The composite sample can then be sent for laboratory analysis.

Up to sixteen CIFA350 measurement systems can be supported by one CIFA350 control cabinet, which is located in a control room or switch room up to 1km cabling distance away from the measurement systems. Communication between each CIFA350 measurement system and the control cabinet is via a single twisted pair of shielded instrument cable. The control cabinet contains an industrial computer which calculates results, provides a user interface, and communicates with the plant. The computer also maintains an extensive log file of all CIFA operations and supports remote user access by dial up modem or via the internet.

Figure 1. - CIFA350 Electronics Module and Measurement Module on a Duct

FEATURES OF THE NEW CIFA350 SYSTEM

The Scantech CIFA350 offers a number of technical advantages over previous carbon in fly ash monitors. The measurement method uses the patented microwave resonant cavity technique originally developed by the CSIRO. The electronics and fly ash handling system have been completely redesigned to provide the following advantages;

- New microwave electronics allows a very precise and stable measurement of the microwave resonance. This allows a density compensated unburnt carbon

- An improved method of vibrating the sample tube eliminates build up and blockage in the sample tube.
- A powerful new air purge heating system ensures that the purge air is heated to above 100 degrees Celsius at all times. This ensures that moisture condensation can never occur in the fly ash pathway.
- A sampling valve and collection canister can be fitted to collect fly ash sample for laboratory analysis when required. When not required it can be removed for safe keeping. A single sampling valve and canister can be shared amongst several CIFA monitors if simultaneous sampling is not required.
- Control of the CIFA monitors is centralised in a control cabinet which can be located up to 1km away in a control room or switch room. Up to 16 CIFA monitors can be connected to a single control cabinet.

PERFORMANCE OF THE CIFA350 AT TARONG

A CIFA350 system has been operating on duct B of boiler 3 at Tarong Power Station since October 2006. The only significant down time was one week due to a failed pneumatic turbine vibrator in December 2006. No electronics failures have occurred. The wear rate on the sample tube and other replaceable parts has been low. Scheduled replacement of wear parts every six months is recommended. In August 2008 three more CIF350 systems were installed on the other three boilers at Tarong.

The CIFA350 was initially calibrated by comparison with laboratory analyses of composite samples saved automatically by the sampling valve. Each composite sample was collected over 40 to 50 minutes and consisted of typically 5 to 8 individual samples. Laboratory analysis used the loss on ignition (LOI) method. The calibration was installed in November 2006 and remained unchanged throughout the trial. Subsequent work showed that the LOI method could produce significant errors. LECO and CHN laboratory methods were found to give much more accurate determination of unburnt carbon. Figure 2 shows the performance of the CIFA350 compared with samples analysed by LECO and CHN methods. A bias of 0.772 %C was present in the original LOI based calibration and this has been removed from the graph. The graph shows a line of x=y to assist in interpreting the results.

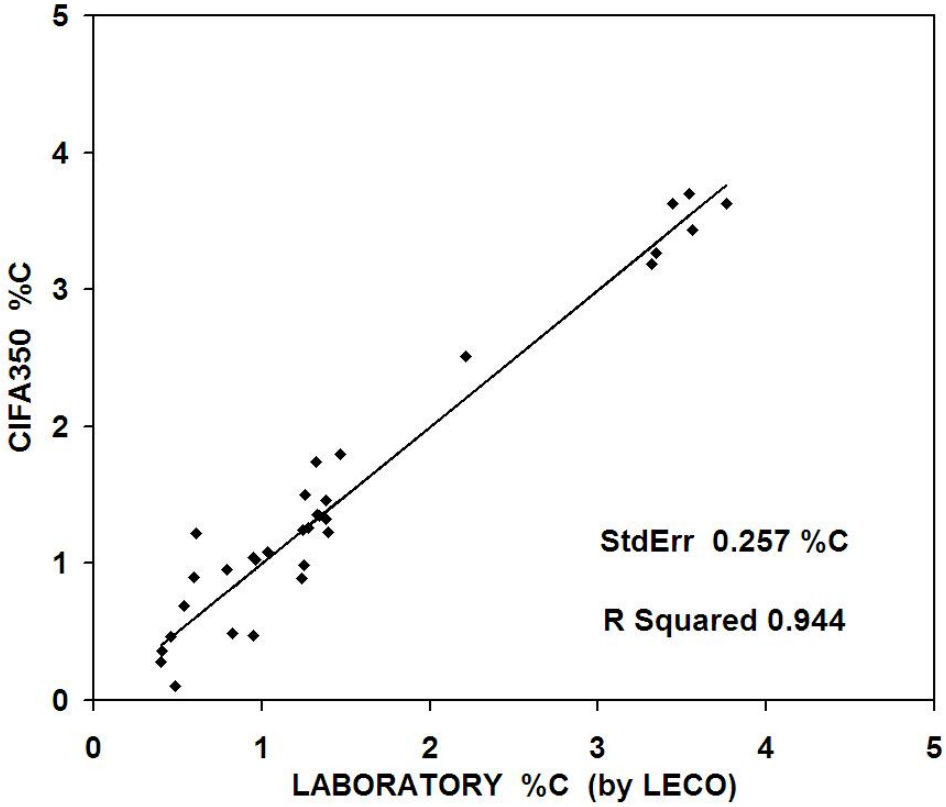

Figure 2. On-Line Performance of the CIFA350

In viewing this graph it is important to appreciate that the scatter of points about the line is due to errors in both methods of analysis. The laboratory data includes errors due to sub-sampling as well as the accuracy of the laboratory analysis method. We can say that the true accuracy of both the CIFA350 and the laboratory analysis is better than the 0.257 %C indicated on the graph.

LOSS ON IGNITION (LOI) AS A MEASURE OF UNBURNT CARBON

The most commonly used laboratory method for determining unburnt carbon in a fly ash sample is the loss on ignition (LOI) method. This method measures the weight loss of a sample when heated in a laboratory furnace for a specified temperature and time. The weight loss is assumed to be due to removal of carbon in the sample by oxidation to carbon dioxide. Boiler operators frequently use the term LOI as an abbreviation for unburnt carbon in fly ash.

The initial calibration of the CIFA350 was done by comparing the CIFA350 data with LOI analysis of samples. The first set of samples gave good agreement however samples collected late gave disappointing results. Figure 3 shows a comparison between the %C measured by the CIFA350 and LOI measurements for 24 samples. In this graph, and subsequent graphs, a line of x=y is shown to assist in interpreting the results.

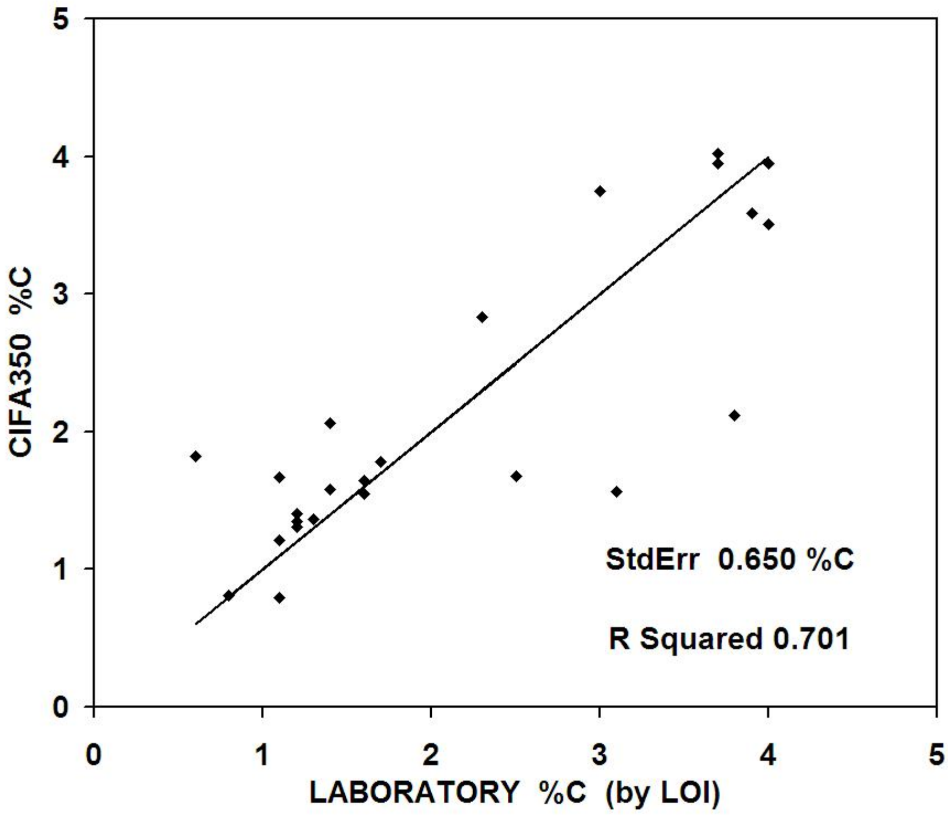

Figure 3. Comparison of CIFA350 with LOI results.

Subsamples of the collected samples were sent for laboratory by the LECO method. This method of analysis makes a more direct measurement of carbon by measurement of the amount of carbon dioxide emitted during heating of the sample. For some of the samples multiple subsamples were taken and sent to a second laboratory for LECO analysis. A small number of samples were also sent to a third laboratory where a %C measurement was made by use of the CHN method. Agreement between the laboratories was generally good, typically better than 0.1%.C.

Figure 4 shows a comparison between the %C measured by the CIFA350 and LECO measurements for the same 24 samples. This shows a greatly improved agreement. The standard error has decreased from 0.650%C to 0.223%C. This indicates that the CIFA350 and the LECO method both provide a better measurement of unburnt carbon than the LOI method.

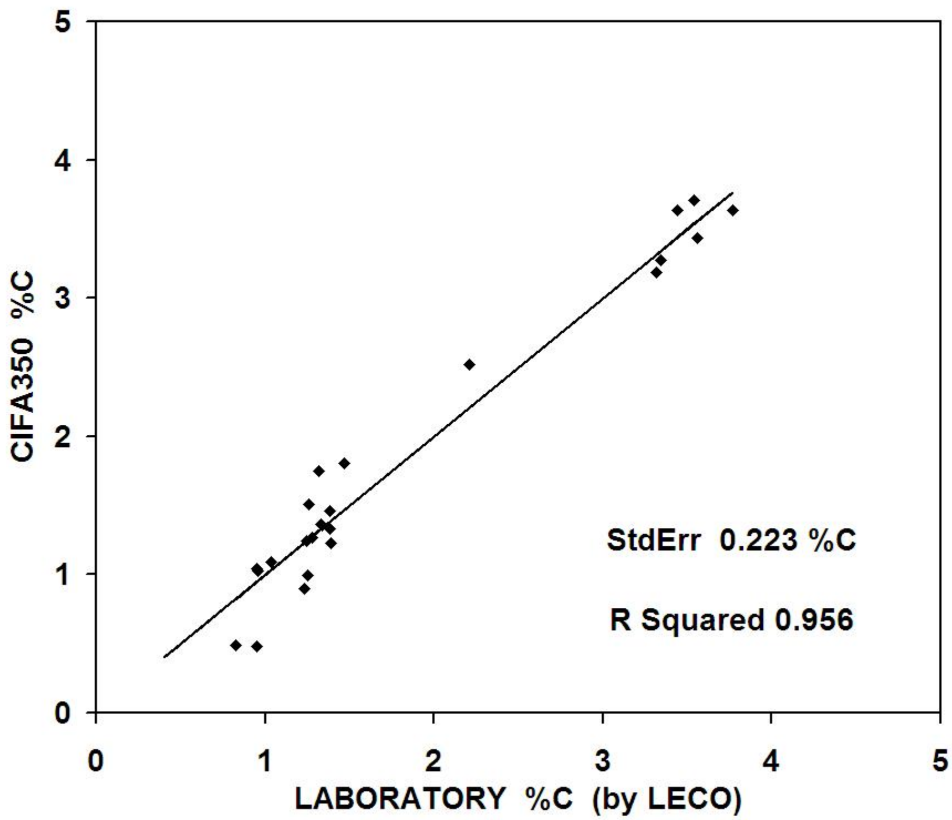

Figure 4. Comparison of CIFA350 with LECO results.

Figure 5 shows a comparison between the LOI measurements and the and the LECO measurements for the 24 samples. Plotting the LOI results against LECO shows a poor agreement. There are a number of possible reasons why a LOI measurement may not give an accurate indication of unburnt carbon. Minerals may be present which dehydrate or decompose on heating and volatile materials may be present, both of which can an over estimate of %C in the sample by the LOI method. (Fan and Brown 2001). These effects may vary significantly from one coal type to another, resulting in a significant variability in the usefulness of LOI as a measure of %C. This may cause problems when a power plant is using LOI to control boiler operation when coals are being derived from a wide range of sources. There is some evidence of coal type effects at Tarong, where good results were obtained form LOI measurements initially, but the LOI data were significantly worse some months later.

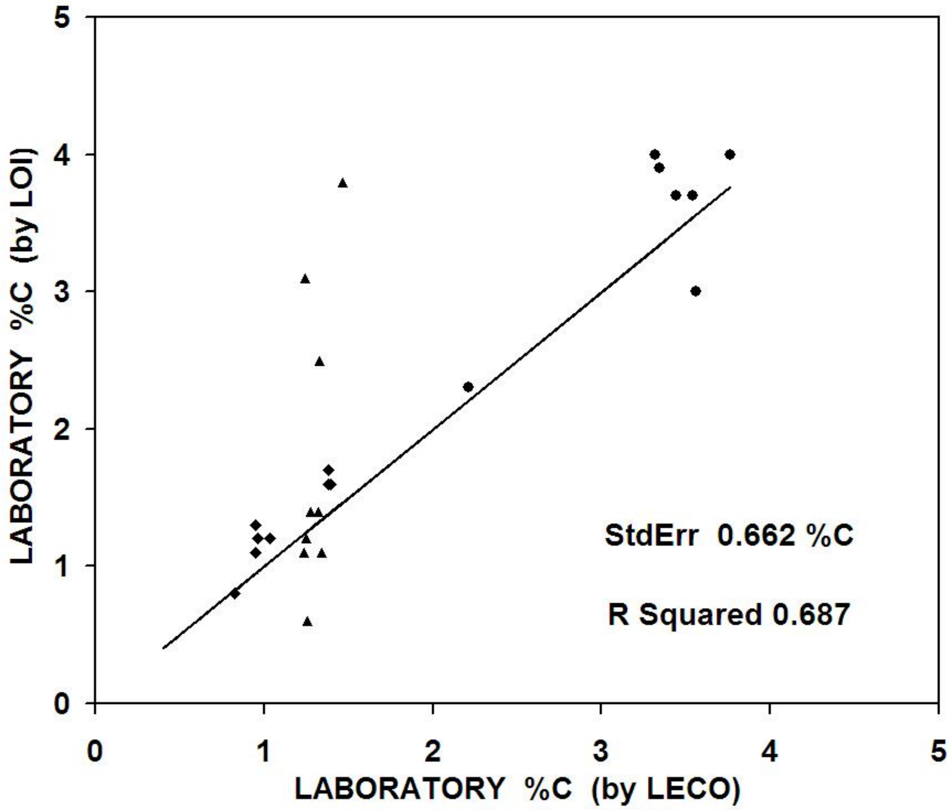

Figure 5. Comparison of LOI with LECO results.

FEASIBILITY STUDY ON FLY ASH SAMPLES

The CIFA350 can be used in an off line mode in order to assess the accuracy achievable in a proposed installation. Typically set of 20 samples are placed in sample tubes and microwave measurements are made by placing the sample tube in the resonant cavity. Good quality laboratory analyses are required for each sample. Comparison of the microwave reading with lab readings allows an estimate of on line accuracy to be made.

CONCLUSIONS

The CIFA350 provides a reliable system for on-line analysis of unburnt carbon in fly ash. The near real time data produced allows boiler operators to respond rapidly to changes in boiler conditions. The accuracy achieved is generally better than the traditional method of predicting unburnt carbon from a laboratory loss on ignition measurement. The CIFA350 may be particularly useful when boiler operators are required to make boiler adjustments to suit coals from a wide range of sources.

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