Using an on-line elemental coal analyzer for improved boiler efficiency

By
Kurt Snider, PacifiCorp
Michael Evans, Thermo Electron Corporation
Richard Woodward, Thermo Electron Corporation

Abstract

On-line coal analyzers have been in use in coal mines, washeries, and coal-fired power plants for almost twenty years. Most of the analyzers used by utilities are used for blending to comply with emission regulations or to verify the quality of coal received. However, in 2002 PacifiCorp undertook a very different application of a coal analyzer, to control the ash fusion temperature to reduce forced outages at its Hunter Station in Utah.

The application required far more information from an analyzer than most are able to provide. In order to estimate the ash fusion temperatures in the coal being sent to the power plant PacifiCorp needed an analyzer that could measure the ash constituents whose proportions determine ash fusion. The Gamma-Metrics Coal Quality Manager (CQM) analyzer from Thermo Electron Corporation provides minute-by-minute analysis of SiO_2, Al_2O_3, Fe_2O_3, CaO, TiO_2, K_2O, and Na_2O in the ash. PacifiCorp installed one of these units in its coal yard to blend coals of differing ash composition, in order to keep the blended coal's ash softening temperature above 2175 degrees F.

In order to take advantage of the potential of this instrument several steps had to be taken. First the analyzer had to be rigorously calibrated and evaluated in the field to verify that the desired accuracy was achieved. Meanwhile the utility had to analyze its boiler characteristics and coal characteristics to be able to derive an ash fusion equation appropriate to the plant. Then the necessary operational steps had to be taken to ensure that source coals capable of achieving the target blend could be initially segregated and then blended at the correct ratios.

After some startup difficulties, the analyzer and the blending system have been very successful in maximizing the ash softening temperatures, and the plant has substantially reduced its forced outages due to slagging while burning a variety of available fuels.

This paper will review the system design, the plant performance history, and the analyzer performance.

Introduction

PacifiCorp owns and operates more than 7,000 mega watts of thermal power generation capacity in 17 plants in the western United States. At PacifiCorp's Hunter Plant, located near Castle Dale, Utah, a Thermo Electron Corporation CQM analyzer was put into service November 2001 for the purpose of controlling the ash fusion temperature of the coal blend to reduce forced outages.

History of the CQM at Hunter Station

The Hunter Plant receives coal by truck from a number of mines in central Utah. As with any coal-fired generation facility, changes in coal quality were affecting the plant's generating capacity. A mine that historically supplied coal to Hunter Plant closed in early 2001, necessitating a fuel switch to a supplier with lower ash fusion temperatures. Low fusion temperatures are a primary cause of unit slagging and unplanned unit outages.

PacifiCorp, working with their consultant Charlie Rose, was able to correlate the ash softening temperature of the coal feeding the Hunter Station with the forced outage rate due to slagging for a particular unit. PacifiCorp had also developed an understanding of the relationships between certain coal ash minerals and the softening temperature of the ash. PacifiCorp and Charlie Rose developed formulas to estimate the ash softening temperature of the coal blend as a function of the components of the ash. Then, based on previous experience with PGNAA analyzers at another PacifiCorp Plant, they realized that with a PGNAA analyzer the chemistry of the six major ash components could be measured and the ash softening temperature controlled.

PacifiCorp justified the analyzer project based on reducing the number of forced outages at Hunter caused by slagging. PacifiCorp purchased a Gamma-Metrics Coal Quality Manager (CQM) analyzer from Thermo Electron. PacifiCorp would use the analyzer to maximize the ash softening temperatures of the coal blends feeding the boilers.

Site Description

Coal is delivered by tandem truck to the site and normally is discharged at the blending system truck dump where it is stored in one of three stockpiles. Coal from the three piles is reclaimed as a blend and conveyed to the screening transfer building. The coal is then conveyed to a second transfer tower and on to a surge bin ahead of the storage barn feed belt. Coal from a second truck dump also discharges into the surge bin. Coal from the surge bin is then conveyed to the storage barn. The CQM was installed on the storage barn feed belt where it could be used to control the blend of coal from the three stock piles and to monitor the quality of the coal dumped at the direct feed truck dump. Figure 1 shows the Hunter Plant coal blending system layout.

Figure 1. Layout of PacifiCorp's Hunter Power Plant Coal Blending Facility

A cross-belt sampler was installed on the storage barn feed belt. The sampled coal from the primary sampler discharges directly into the feed hopper on the CQM. The CQM controls the feed of coal through the analyzer and the sample system with a variable speed belt and discharges it, via a chute, into the sample crusher. The crusher discharges coal on to the secondary feeder belt. A two way cross-belt secondary sampler located on the secondary feed belt allows two samples to be collected from the belt in separate sample containers. The secondary feed belt discharges reject coal onto the sample reject conveyor which transports it back to the barn feed conveyor. Figure 2 shows the system as it is installed.

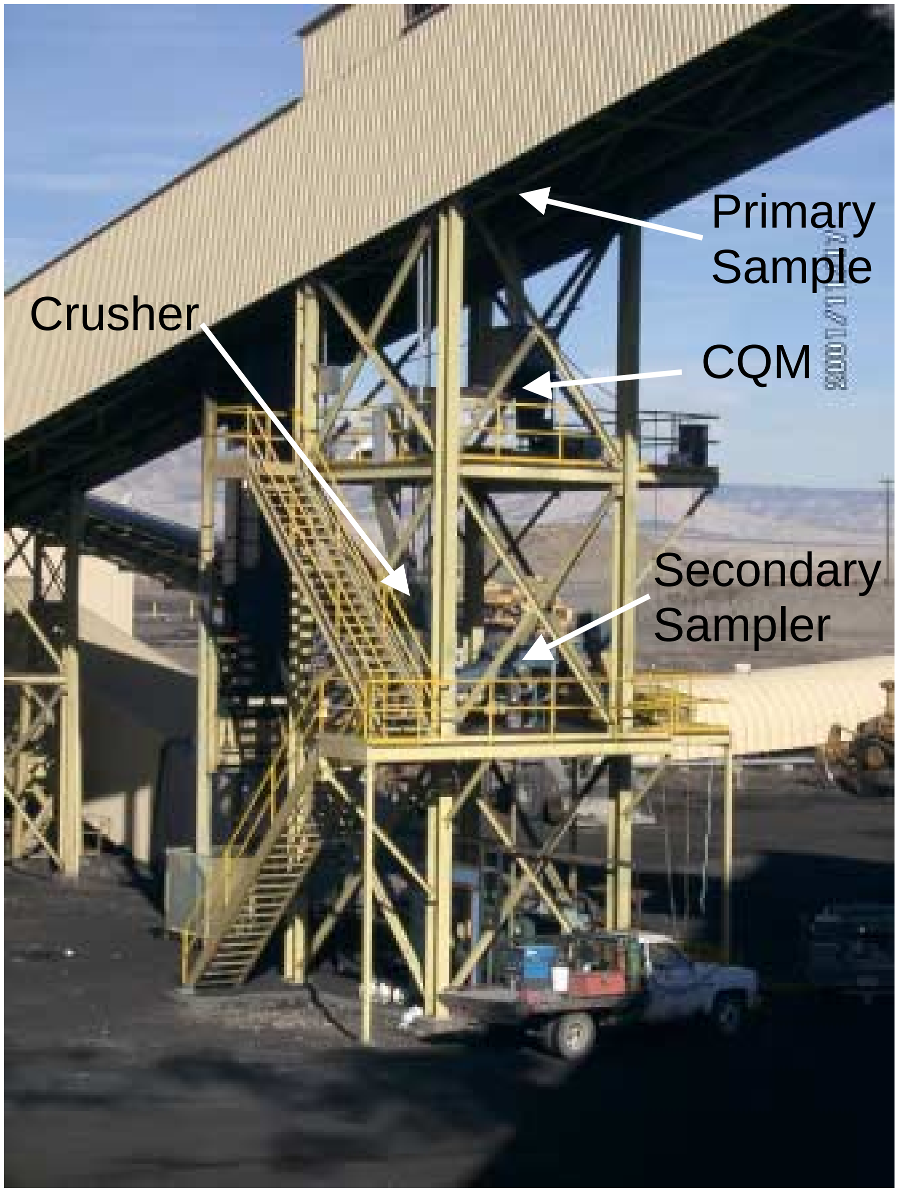


Figure 2. Sample system and CQM installed on the Storage Barn Feed Belt

The Sample system and the CQM were started up in November of 2001.

PGNAA Technology

Prompt Gamma Neutron Activation Analysis (PGNAA) is the best technology available to perform on-line analysis of coal to determine the major elements of interest in the coal ash. Because PGNAA measures the elements in the coal it is also an excellent means of determining the sulfur content. The only other known technology capable of measuring the elemental composition of coal is x-ray fluorescence. X-rays have very limited penetration capability, which means that it is primarily a "surface measurement technology". In contrast PGNAA penetrates the entire sample volume thereby representatively analyzing the full stream of coal.

PGNAA relies on the fact that when thermal neutrons are absorbed into the nucleus of an atom, the atom's nucleus briefly becomes unstable and then re-stabilizes by emitting a gamma ray. Each element emits a unique gamma ray signature as it returns to a stable state. Furthermore each element has a different tendency to absorb neutrons. To be measured, the element must have a high likelihood of absorbing a neutron (a high thermal neutron cross-section), and it must emit a gamma ray within the energy window being analyzed. The element must also have enough atoms present in the sample that the probability of that element being impacted by a neutron is sufficient to be detected (this is a function of the amount of material being analyzed and the percentage of the element in that sample). Fortuitously, in coal the elements of interest -- sulfur, silicon, aluminum, iron, calcium, titanium and potassium and, if the percentage in coal is high enough, sodium -- meet all the above criteria. These elements make up the major ash oxides and by summing the ash oxides the percentage of ash in the coal can be determined.

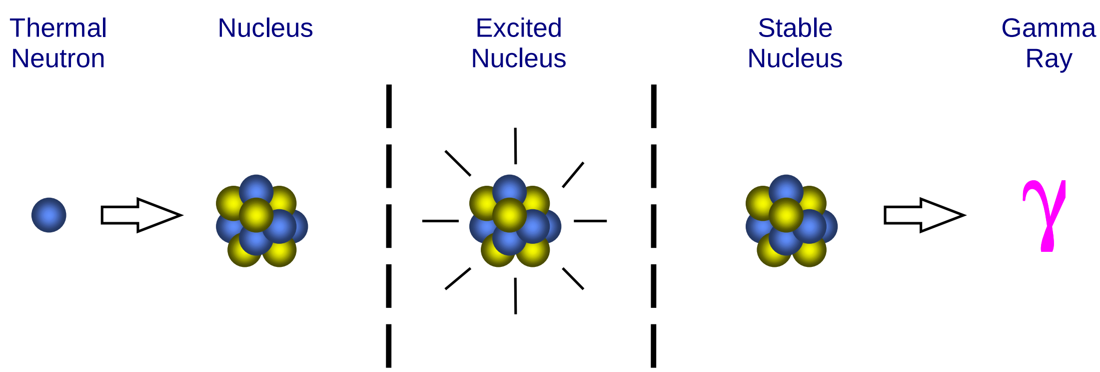


Figure 3. The PGNAA process at the nucleus level

Most PGNAA analyzers use californium-252 as the neutron source. Hydrogen in the analyzer and the sample slow down the fast neutrons emitted by the Cf-252 until they are thermal neutrons traveling at a speed that allows them to be absorbed into the nucleus of an atom. A sodium iodide crystal is used to measure the energy of the gamma rays emitted by the atoms in the sample. The energy signals are gathered into a histogram of the number of gamma rays seen at each energy level for one minute. This is the "spectrum" that is then analyzed.

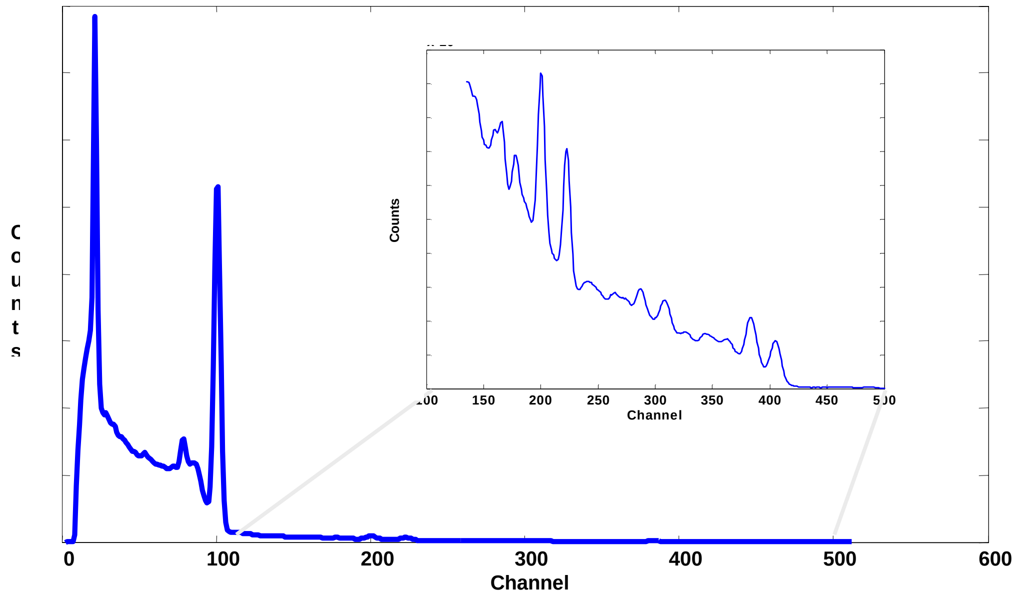


Figure 4. Typical PGNAA Gamma Ray Spectrum for coal

Thermo Electron calibrates each detector crystal to develop the spectrum response for all elements that will be seen in the coal. Then each analyzer detector is calibrated in the factory with carefully designed standards in a manner that eliminates all inter-element correlations. The result is a very robust calibration that is not coal source dependent. This is especially important for the power generation industry as coals from multiple sources and seams are commonly found in each plant. Thermo uses a library of least squares fitted to the spectral responses of each element to determine how many kilograms of that element had to have been in the sample to generate the spectrum measured by the analyzer.

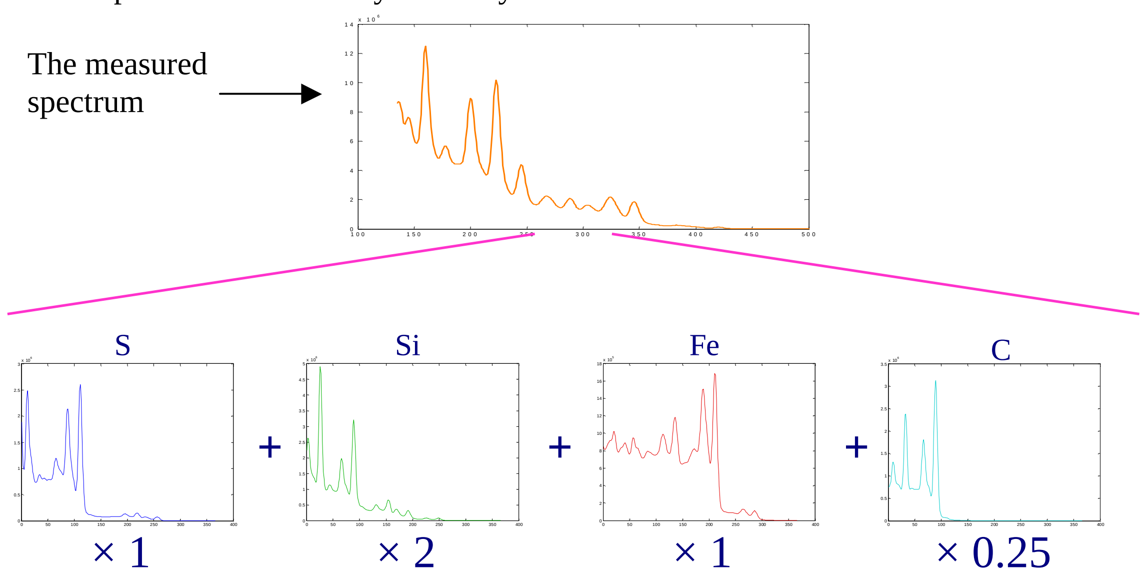


Figure 5. How least squares uses the spectral response of each element in the sample to determine the kg of each element required to match the spectrum (top) measured.

Because the Thermo Gamma-metrics CQM controls the geometry of the coal flowing through the analyzer, it achieves the best possible accuracy.

The Results at Hunter

Approximately one year after the commissioning of the analyzer and sample system, a three-way validation test was conducted to evaluate the performance of the analyzer on its analysis of the ash, sulfur and the ash oxides. Kurt Snider managed this testing and Charlie Rose conducted the statistical evaluation of the data.

The validation test consisted of collecting two independent samples from 45 one-hour runs of coal and comparing the laboratory results with the analyzer readings for the same sample period. The samples were analyzed for moisture, ash, sulfur, ash oxides and ash fusion temperatures at PacifiCorp's Central Fuels Laboratory operated by Commercial Testing & Engineering Company. The statistical analysis results determined whether the analyzer met the guaranteed and expected precision for the coal characteristics of interest.

The results of the test, Table 1, show that the precision of the PGNAA analysis of ash, sulfur and ash oxides at Hunter was exceptional. The statistic used to assess analytical performance was Grubbs' Estimator, recommended in ASTM 6543, the standard for assessing performance of on-line coal analyzers. The Grubbs' Estimator is an unbiased one-sigma precision estimate.

Table 1. Grubbs' Estimator from Hunter validation test

	Sulfur	Ash	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	TiO_2	Moisture
Grubbs' Estimator precision with the field calibration	0.026	0.265	0.194	0.113	0.018	0.069	0.018	0.007	0.789
Grubbs' Estimator precision with a calibration adjustment based on the test data.	0.025	.0204	0.124	0.101	0.019	0.032	0.014	0.004	0.968

The validation test also measured the accuracy of the ash softening temperature formula. Using data from the test Charlie Rose and PacifiCorp were able to determine an optimal calibration for the ash oxide analysis from the CQM. As shown in Figure 6, the results were a much-improved estimate of ash softening temperature.

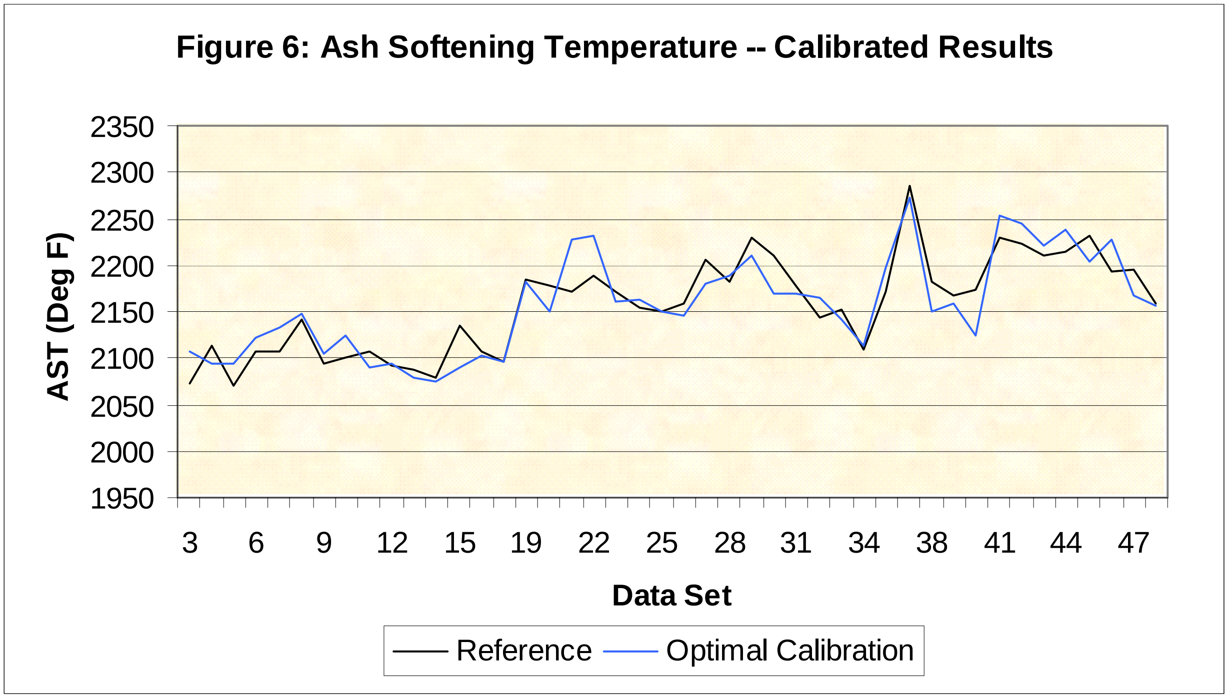
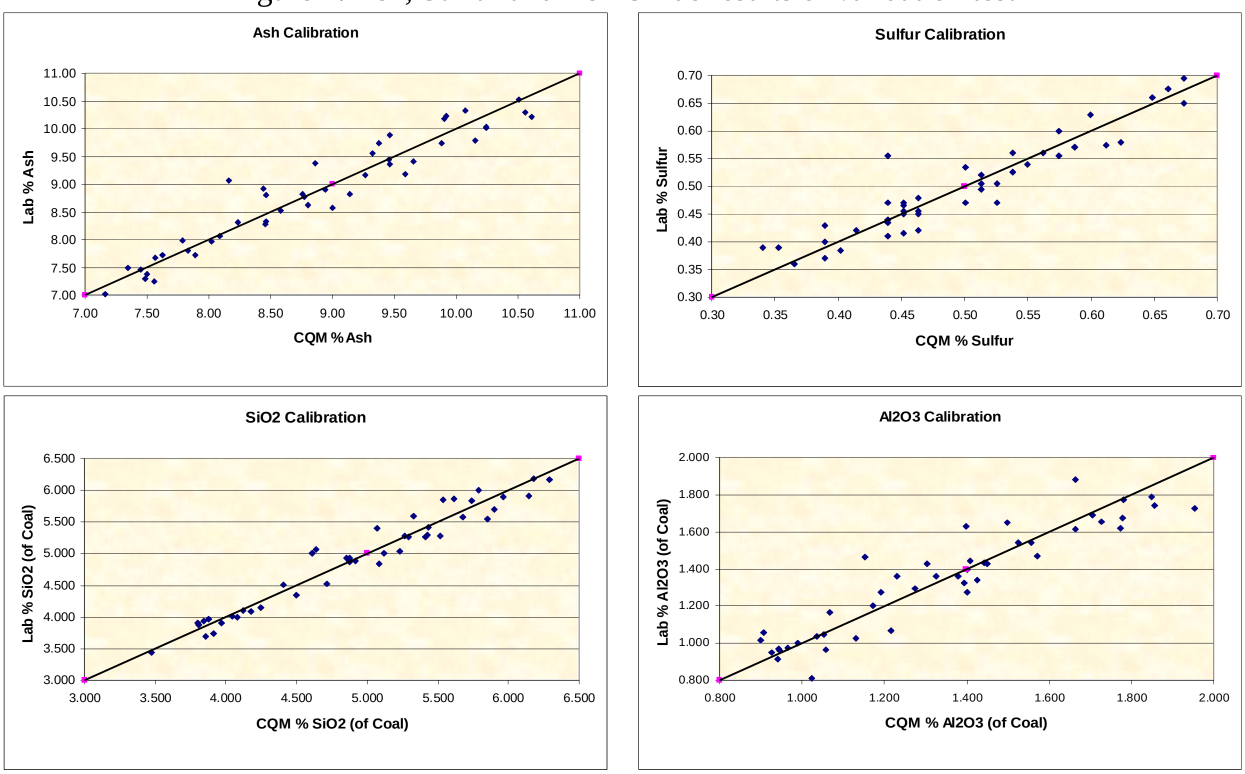
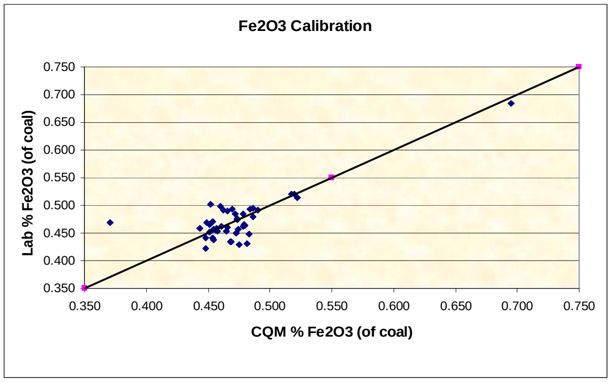
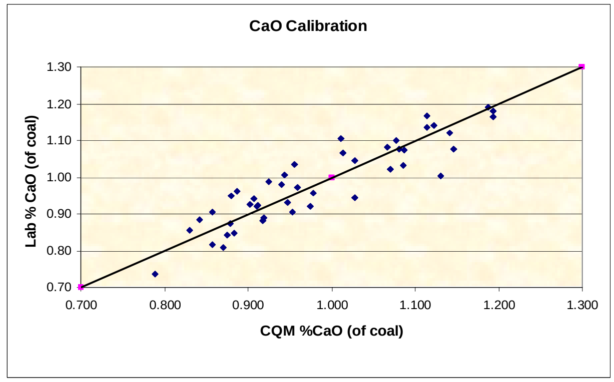
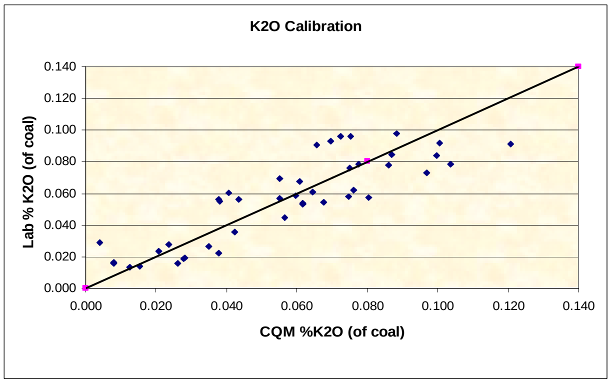


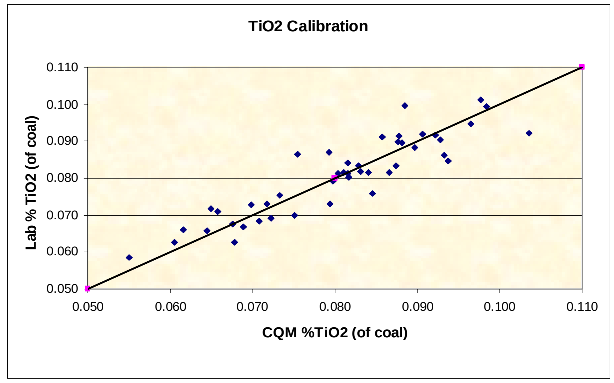
Figure 7. Ash, Sulfur and Ash Oxide results of validation test











Value Seen by PacifiCorp from having the analyzer

PacifiCorp has obtained significant value from the analyzer, some foreseen and some unexpected. First, the intended objective of reducing the forced outages at the plant by controlling the ash fusion temperature of the coal has been achieved. The availability at the Hunter Station has improved since the CQM has been used for precise blending control. Minute-by-minute data from the analyzer has allowed the plant to supply more consistent coal blends to the units and has allowed the plant to maximize the ash softening temperature of the blend, while reducing the need for more expensive, high fusion coals.

Secondly, with more reliable coal blend Hunter Station has re-gained electrical generation capacity and more consistently achieved the maximum rated capacity of the plant due, in large part, to using the CQM as a tool to control coal quality. Hunter Station can now more effectively burn fuels from a variety of sources. Figure 8, shows unit availability before and after the CQM was used for blending coals.

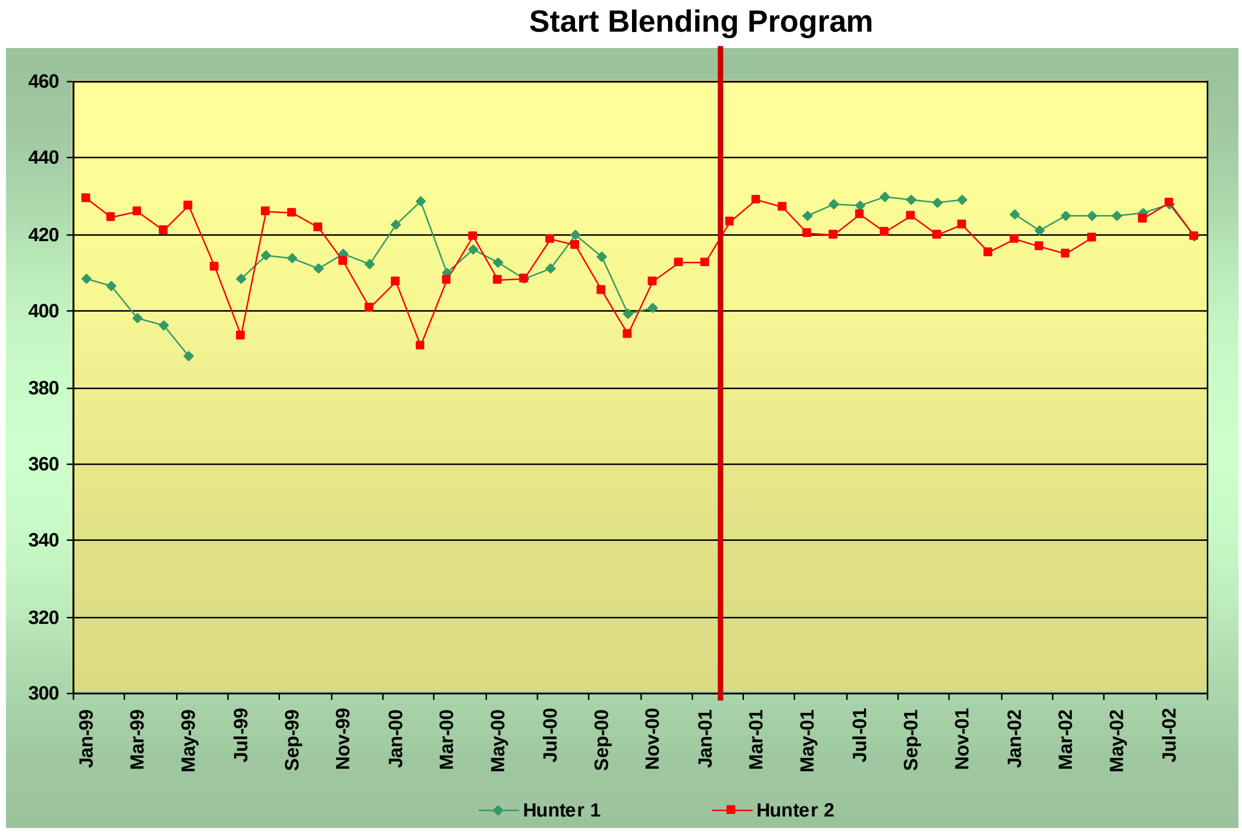


Figure 8. Unit availability before and after blending program started

Third, the CQM allows the plant to closely monitor the quality of the coal being delivered to the plant by their fuel suppliers; the consistency of the delivered coal has improved. Steve Cowan, General Manager, Fuel Handling for Hunter Power Plant, states “I can catch the truck before it leaves the property if the coal supplied doesn’t meet the contract specifications for that supplier”.

Finally, an unexpected bonus has been the quicker identification and correction of equipment problems in the plant. In the past, plant operations problems were often blamed on fuel quality, which was not known in real time. It would take at least a day for coal sample analysis results to come back from the laboratory. Now when operating problems occur, it can be immediately determined whether or not there is a coal quality issue. If not, the plant can quickly move on to identify the true source of the problem and fix it. There is less potential for lost generation because both quality and equipment problems are identified and addressed sooner.

Summary

PacifiCorp’s Hunter Power Plant in Utah, faced a recent coal quality challenge, and took the bold and unprecedented step of using an on-line coal analyzer to control the ash softening temperature of the blended coal. The results, in terms of reduced outages and improved plant efficiency, have rewarded this ambitious decision.