Using an On-line Nuclear Analyzer to Optimize the Operation of a Coal Burning Power Plant

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Abstract

The Dayton Power and Light J.M. Stuart Power Station is one of the early adopters of on-line nuclear elemental analyzers, successfully using an online unit to optimize the plant operation. J.M. Stuart Station was built in the 1970's and consists of four positive pressure, supercritical, 605 Mwe nominal units that have been retrofitted with SCR's. These units process over 6,600,000 tons of coal per year. The innovative team at Stuart Station has implemented a well thought out program to utilize the on-line nuclear analyzer technology throughout their processes, beginning with timely screening of the coal coming in on barges. The team at Stuart Station has teamed with a combustion consultant and the analyzer vendor under the same contract to also utilize the technology for boiler optimization. The DP&L team is already benefiting from accurate real-time visibility of incoming coal and is evolving boiler slagging indices from the dynamic analyzer data to use in overall plant optimization. This paper takes a look at both the technical details of installing and using a nuclear analyzer as well as some promising aspects of boiler optimization and associated economics.

** Nuclear Elemental Analyzers as defined for the purposes of this paper are those analyzers that measure the individual elements of the periodic table. For example, Ash is determined by adding the sum of the individually measured constituents of Ash, i.e., Silicon, Iron, Calcium, Aluminum, Potassium, Titanium, etc…

Introduction to J.M. Stuart Station
Real-time coal analyzers – why use one?
How they work
The installation
What do they provide?
Using the data
Some Do's and Don’ts
Looking ahead
Summary

Introduction

The Dayton Power and Light Company, J.M. Stuart Station, located on the Ohio River just outside of Aberdeen, Ohio, was built in the early 1970's. With four 605 MW units, the station is ranked 20th in the United States for coal-fired generation. The station processes over 6,600,000 tons of coal per year and burned its 200 millionth ton of coal in 2005. The aerial photograph below shows the entire generating facility and its fuel transportation artery, the Ohio River:
The coal arrives via barge fleets from a variety of suppliers up and down the river. Historically the plant has utilized an existing mechanical sampler associated with the barge unloader to sample the coal as it is offloaded from the barges. The problem with this has been the delay of several days to two weeks to get lab results. In 2004 the station unloaded 7,000,000 tons, the equivalent of 3950 barges. The plant operates 24 hours a day, 365 days per year with up to 50% of the unloaded coal going directly to the units. Unloading of a barge requires approximately 45 minutes. The plant has 24 storage silos which provide an 8+ hour storage capacity at full load. A plan view of the plant layout is shown in figure 2. below:
Figure 2. The J.M. Stuart Station Overall Layout

Figure 3. The Fleet of Barges
Figure 3. A typical fleet of loaded barges await unloading on the Ohio River

Figure 4. A continuous bucket unloader moving coal out of a barge

Figure 5. The conveyor and coal stacker tower downstream of analyzer
As with many coal burning electric power generating facilities, J.M. Stuart Station faces the increasingly difficult job of maximizing the number of hours the generators are on-line, generating revenue while wrestling with the need to utilize larger numbers of suppliers to offset the increasing cost of fuel. The coal specification Stuart Station operates under is shown below:

**Stuart Coal Specification**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Today Preferred</th>
<th>Today Min/Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Value – Btu</td>
<td>11,500</td>
<td>10,500</td>
</tr>
<tr>
<td>Ash #/MMBtu</td>
<td>11.3</td>
<td>15.24</td>
</tr>
<tr>
<td>Moisture #/MMBtu</td>
<td>8.69</td>
<td>9.52</td>
</tr>
<tr>
<td>SO2 #/MMBtu</td>
<td>-</td>
<td>1.2 – 3</td>
</tr>
</tbody>
</table>

Figure 6. Coal transfer points before the generation plant

Figure 7. J.M. Stuart Station Coal Specification
Combined with a wide variety of operational indicators, Stuart Station uses a weekly steering committee review of 16 Key Performance Indicators (KPIs) to optimize the overall coal operation. Below is a screen capture of eight of the indices:

Table 1: Key Performance Indicators (KPIs) Reviewed Weekly

<table>
<thead>
<tr>
<th>Indice Name</th>
<th>Goal</th>
<th>Actual</th>
<th>Actual Date (frequency)</th>
<th>Performance Highlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housekeeping &amp; Safety (B/W)</td>
<td>&gt; 80%</td>
<td>84%</td>
<td>4/24/2005 (weekly)</td>
<td>Great job improving housekeeping and safety. Thanks for the clean up efforts.</td>
</tr>
<tr>
<td>Fuel Cost of Coal (M)</td>
<td>&lt; $44.00</td>
<td>$4</td>
<td>4/30/2005 (monthly)</td>
<td>Beginning inventory value was $4___ per ton and ending value was $4___ per ton.</td>
</tr>
<tr>
<td>Barges Unloading Performance (W)</td>
<td>&gt; 100%</td>
<td>103%</td>
<td>5/9/2005 (weekly)</td>
<td>Great job of turning the barges we received in spite of unloader and storage problems.</td>
</tr>
<tr>
<td>Coal Quality (W)</td>
<td>100%</td>
<td>100%</td>
<td>5/9/2005 (weekly)</td>
<td>All of the barges unloaded during the week met spec according to online analyzer.</td>
</tr>
<tr>
<td>Barge Turnaround (W)</td>
<td>&lt; 24hrs</td>
<td>27hrs</td>
<td>5/9/2005 (weekly)</td>
<td>Barge #454 that was originally rejected based on the online analyzer and held in</td>
</tr>
<tr>
<td>Unloader Availability (W)</td>
<td>&gt; 95.0%</td>
<td>72.7%</td>
<td>5/9/2005 (weekly)</td>
<td>Had to remove a bucket that had a torn tip and caused the DB string to fail. Also</td>
</tr>
<tr>
<td>1500 System Availability (W)</td>
<td>&gt; 80.0%</td>
<td>100.0%</td>
<td>5/9/2005 (weekly)</td>
<td>Great job getting the 1500 availability back up after problems the previous week.</td>
</tr>
<tr>
<td>Tons Received vs. Tons Shipped</td>
<td>0.25%</td>
<td>0.25%</td>
<td>5/9/2005 (weekly)</td>
<td>Received 138,704 tons according to H3 scale and paid for 138,962 tons according to FMS.</td>
</tr>
</tbody>
</table>

Figure 8. Eight of the 16 Key Performance Indicators (KPIs) reviewed weekly

Fifteen of the indices are:

1. Housekeeping and Safety 1
2. Fuel Cost of Coal
3. Barges and Unloading Performance
4. Coal Quality
5. Barge Turnaround
6. Unloader Availability
7. 1500 System Availability
8. Tons Received vs. Tons Shipped
9. Housekeeping and Safety 2
10. Return to Service
11. Commercial EFOR
12. Equivalent Availability
13. I/O Heat Rate
14. Boiler Water Chemistry
15. Boiler Water Specific Chemistry
Real-time coal analyzers – why use one?

In 2004 boiler slagging was the greatest EFOR (equivalent forced outage rate) component. With the normal time delay in sampling and lab analysis it was realized that more data and more timely data was needed in order to reduce the boiler slagging component of EFOR. It was decided that the greatest chance for success lay in the form of PGNA technology – an on-line nuclear analyzer that is a true elemental analyzer, measuring sulfur, total ash and the ash constituents in real-time and presenting them to the operators for use in process control decisions. The key managers reasoned that many coal mines utilized this same technology but few coal burning utilities had. These same managers who made the decision to buy an on-line PGNA analyzer realized that with coal prices being at $30/ton at the time the power replacement costs were $15,000 per hour. The math was simple enough – the power replacement costs of one major outage covered the purchase of a new analyzer. In order to optimize use of the real-time coal composition information to be made available with a new on-line analyzer the management of Stuart Station secured the services of a combustion consultant in the form of General Physics.

What is PGNA? – A Brief History of PGNA Analyzers

As a result of the pioneering work of Bob Stewart at the Bureau of Mines in the 1970’s and further research under grants from the federal government and from EPRI in the 1970’s and 1980’s it became possible to introduce a commercially viable nuclear elemental analyzer in the mid-1980’s.

The technology uses a technique known as prompt gamma neutron activation (PGNA). In this process a spontaneous fissioning nuclear source such as Californium 252 is used to bombard a sample to be analyzed with massive quantities of neutrons – several hundred thousand per second. In turn, the elemental atoms in the sample capture a large number of the incident neutrons. These atoms become unstable but quickly re-stabilize by emitting an array of gamma energies. Since each element emits a unique set of gamma energies, spectral analysis identifies which elements are in the material. As a true elemental analysis technology, it can measure on-line and in real time the quantities Silicon, Calcium, Aluminum, Iron, Titanium, Magnesium, Potassium, Sodium, and Sulfur, as well as Chlorine, Nitrogen, and Hydrogen.

The first successful version of these instruments was “chute-type” analyzers that required a gravity-feed of the producer’s crushed quarry materials from the top of the unit onto an exit conveyor underneath the unit. The basic sticker price for these units was as much as $1.0M. With the costs of mounting the unit and getting the cement into and out of the unit taken into consideration, the total cost of ownership often topped $1.5M. Versions are now available for around $200K with very minimal associated construction costs. Below is a timeline of the development of the technology:
The PGNA Development Timeline

1985  First chute-type nuclear elemental analyzer available commercially – first successful units placed in coal and cement
1986  Ad appears for PGNAA analyzer
1987  Initial units expensive – analyzer priced at $800K + $500K to install
1988  Most of the initial market penetration is in coal segment
1989  A few installations yield payback in less than 12 months
1990  Two major vendors selling PGNAA analyzers. Calibrations are site specific – in coal there is trouble with multiple seams
1991  IEA Survey shows 30 PGNAA chute-type units sold –
1992  Price/Performance Ratio makes many purchases hard to justify
1993  Slurry Analyzer Introduced in rock
1994  First belt-type version offered for cement
1995  Lab version of PGNAA announced
1996  One main vendor dominates market with over 70% of sales
1997  Hybrid chute/belt unit introduced – vendors develop well designed factory calibration standards to allow for robust calibrations that can handle a wide variety of coal seams or variations in quarries
1998  Units begin to gain widespread acceptance – 30 to 40 sold per year – much less nuclear source needed without sacrificing performance
1999  New vendor lowers price tag significantly for cement – prices begin to come down – three major vendors
2000  Over 100 units sold – now 4 major vendors selling services and products
2001  First belt version for coal introduced
2002  Low-cost belt version for coal introduced – units are built using the latest in computer technology – analyzers can be viewed via the internet
2003  Version developed for mounting on conveyor – prices continue to drop
2004  High performance, easy to install versions now available for less than $250K US
2005  The technology has gained widespread acceptance although there are still occasional applications with poor results – these are usually the result of misapplication of the technology
2006  Nearly 300 units sold in cement, coal, and minerals industries – the market is no longer dominated by one vendor – market share spreading out and beyond – The technology will continue to shrink in overall bulk and the existence of multiple vendors will continue to put pressure on pricing to the benefit of coal handling customers. Source strength should continue to come down with no negative effect on performance.

Figure 8. PGNA development timeline
How They Work

**Basic Principles**
When a bulk material such as cement is bombarded with thermal neutrons, (<1 electron volt neutron energy), from a Californium 252 nuclear source, many of the neutrons are captured by elemental atoms within the cement. When this happens the atom becomes temporarily unstable. In order to re-stabilize the atom sheds a spectrum of high-energy gamma rays. The specific energies of gamma rays given off are a unique set for each of the elements within the periodic table. This principle makes it possible to create a signal to enable the on-line elemental analysis of cement possible with PGNA.

**Obtaining and Processing the Signal**
In order to create an electronic signal used for the determination of the weight percent of the elements of interest within the cement the unique elemental signature gamma rays resulting from the capture of neutrons by elemental atoms are detected by a scintillating crystal such as Sodium Iodide (NaI). As the gamma rays penetrate the detector they deposit their energy as high-speed electrons within the crystal. These electrons create ionization, which can be detected as UV light pulses. The light pulses are in turn detected by photo-multiplier tubes (a vacuum tube electronic component operating at a high voltage, typically 500 to 1000 VDC) and turned into electrical pulses which are immediately amplified, shaped and then converted into digital signals, and collected into a spectrum over some predetermined period of time (typically one minute) which can then be processed by a computer at very high speeds.

![Figure 9. The Nuclear Physics of PGNAA](image)

**Processing the Spectrum**
The resulting gamma-ray spectrum collected over a one-minute period is actually a distribution of all the incoming gamma-ray energy levels ranging from zero to ten Mev (Million electron volts). In cement applications anywhere from five to fifteen elements of interest are represented in the spectrum. A typical spectrum is shown below which over in one minute collects several million pulses.
Intuition says that arriving at the weight percent of each element could be accomplished with a simple evaluation of the size of each of the peaks, which is not the case. The MLR approach takes into account the entire shape of all the elemental peaks. Most commonly, vendors use a full-spectrum analysis such as Library Least Squares that utilizes the instrument response to pure elements used as a library against
which the incoming spectral data can be compared on a minute-by-minute basis. Typically a multiple linear regression technique is used which solves a linear matrix equation with matrix inverse math. With the high speed and data capacity of computers available today, the time required for this mathematical treatment (de-convolution of the spectra) of the data takes only seconds and becomes transparent to the end user. Prior to presentation of the final answers to the cement producer, the results of the multiple linear-regression are normalized with respect to each other. The technology has made significant strides and now offers the marketplace impressive precisions and accuracies. **Today's analyzers calibrated in the factory with an orthogonal set of synthetic coal reference standards arrive at the site calibrated for the universe of possibilities in coal.** This means that the analyzers can be immune to changes in raw-material types.

The technology is highly accurate, with accuracies of 0.05% for sulfur and 0.50% for ash. Below is a table of sensitivities for many of the elements in the periodic table:

<table>
<thead>
<tr>
<th>Sensitivity in Weight % **</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.01%</td>
<td>Cl, Sc, Ti, Ni, Cd, Hg, Sm, Gd, Dy, Ho</td>
</tr>
<tr>
<td>0.01-0.1%</td>
<td>S, V, Cr, Mn, Fe, Co, Cu, Rh, Ag, In, Hf, Ir, Au, Nd, Eu, Er, Yb, H</td>
</tr>
<tr>
<td>0.1-0.3%</td>
<td>N, Na, Al, Si, K, Ca, Ga, Se, Y, Cs, La, W, Re, Os, Pt, Pr, Tm</td>
</tr>
<tr>
<td>0.3-1.0%</td>
<td>Li, Be, Mg, P, Zn, As, Mo, Te, I, Ta, Pb, Ce, Tb, Lu, Th, U</td>
</tr>
<tr>
<td>1.0-3.0%</td>
<td>C, Ge, Br, Sr, Zr, Ru, Pd, Sb, Ti</td>
</tr>
<tr>
<td>&gt;3.0%</td>
<td>Other Elements</td>
</tr>
</tbody>
</table>


** Three sigma detection limit in 10 minutes within an elementary simple rock matrix, ≥150mm thick

Figure 12. Sensitivity of PGNA

Figure 13. A version that mounts on existing conveyors
The Installation in Photos

Below are photos of the installation of the PGNA analyzer at Stuart Station:

Figure 14. The Analyzer in place

Figure 15. The associated moisture meter enables calculation of BTU
Figure 16. A plow installed to ensure large clumps of coal don’t make their way through the analyzer

Figure 17. Building just after barge unloader - the analyzer is located in
Figure 18. Beige building used for location of the analyzer computer

Figure 19. Analyzer computer inside the protective building
What data do they provide?

The PGNA Analyzer provides a wealth of elemental information on a minute-by-minute basis. All of the incoming signal from the raw coal on the incoming conveyor is stored as gamma spectral information and can be referenced at any time in the future. Because it is the raw spectrum, to replay it is like running the coal again. The customer’s combustion consultant utilized their existing information management system, “Eta” to take elemental results directly from the PGNA analyzer and display to the customer in real time trend graphs for management of his processes. Below is a summary screen for 1 minute of data on incoming coal:
Figure 21. Manager’s command center

Figure 22. Ash with Alarm Limit

Figure 23. Base Acid Ratio with Alarm Limit

Figure 24. Silica Alumina Ratio

Figure 25. Iron Trend

Figure 26. Slagging Factor with Alarm limit
Using the Data

Stuart Station has used the real-time data to reject incoming barges and are certain that vendors are taking greater care to meet contract targets. The analyzer has proven itself to be an important quality control tool with more data available than ever before. The real-time data without the two week time delay has proven very useful and some myths about fuel quality have been dispelled.

Some Do's and Don’ts

Do

- Use a Combustion Consultant
  - Early site survey to determine location
  - Pay attention to installation "details"
  - Address ALARA design issues
  - Communicate Radiation Issues Early & Often
  - Order radiation survey instrument kits

Don’t

- Underestimate data communication issues

Looking Ahead

To further utilize the information from the analyzer Stuart Station has installed a data link directly to the unloader cab for local alarming of out-of-spec coal. The unloader operator now inputs the barge number and the start and stop unloading times. Local alarming includes a high slagging index.

Figure 27. Unloader cab and analyzer building
Additional future tasks include a complete redo of the data summary screen for ease of use, revision of the slagging indices to a single weighted alarming metric for simplicity, providing early warning for operators, and identifying unique slagging correlations. Stuart Station will be changing the on-site sampling procedure and revising their coal specifications, identifying slagging factors specific to Stuart Station and tightening up on the variation. The data collected by the analyzer will be utilized to produce the average barge analysis data that will be electronically uploaded into the Company’s computerized fuel management system.

**Summary**

It is still early in Stuart Station’s journey to use cutting edge technology to optimize operation, reduce costs and maximize profitability, but the experience so far with PGNA coupled with the advice of a combustion consultant expert has proven beneficial. As it relates to boiler uptime and performance the management at Stuart Station has correctly identified the culprit as variation and they are well on their way to reducing variation and getting complete control of their fuel handling.

**REFERENCES**


