Strict implementation of International Standards for representative sampling of coal is difficult for routine monitoring, due to time, technical, and economic constraints. A large percentage of the total sampling variance arises from errors accumulated during the earlier stages of sample collection. Modified procedures on the precision of the final result leads to controversies between the sellers and customers for coal. Manual collection of coal samples violates the principle of correct sampling, that all fragments must have an equiprobable chance of being in the sample. In addition, manual size reduction of large numbers of samples is time consuming and involves human errors. A coal quality management procedure in alignment with the relevant ISO standards that describes the sampling protocol has been implemented, and current sampling and laboratory analysis of coal from base load mines (mines situated at the mouth of the power station) are well established. For import coal, sampling is performed during unloading by auto-mechanical sampling (AMS). Due to logistical and safety issues associated with multiple suppliers, Eskom opted for the coal to be sampled at source on a pre-certification basis. Online analysers provide a fast, accurate, real-time method of determining the total moisture and elemental composition of coal and is important to the coal industry for pricing, quality control, and reduction of SO2 emissions. Elemental analyses include S, Si, Al, Fe, Ca, Na, Mg, Mn, Ti, K and Cl. Measurement of S is dictated by the control of SO2 emissions from coal-fired power plants. Elements such as Na and Cl have adverse effects on boilers, causing fouling and slagging. Available online elemental analyser technologies include prompt gamma neutron activation analyses (PGNAA), recommended for major element determination, and pulsed fast and thermal neutron analysis (PFTNA), that is capable of measuring the major and minor chemical elements contained in coal. These systems utilize nuclear reactions to produce characteristic gamma rays that are used for identifying various chemical elements. By acquiring the gamma rays in three different time windows, there is a significant reduction of the background as compared with the spectra taken with a radio isotopic source.

**Introduction**

Coal consists of particles of varied shapes and sizes each having different physical characteristics, chemical properties and residual ash content. A correct and representative sample requires that every particle in a lot being sampled is equally represented. Coal sampling protocols must provide material which when analysed will provide results that are representative of the lot sampled. A representative sample is collected by taking a definitive number increments, periodically throughout the entire coal lot being sampled. The number and weight of increments required for a desired degree of precision depends on the variability of the coal which increases with increasing impurities. It is imperative that the minimum specified weight and the minimum specified number of increments are not reduced. There are International Standards for executing the job of representative sampling pertaining to different methods of sampling. However, due to time, technical and other economic constraints strict implementation of the procedures are difficult to practice for routine monitoring. It is a known fact that about 80% of the total variances involved at the different stages of sample collection, preparation and analysis come from errors during its collection. The important issue that is not always considered is the effect of modified procedures on the precision of the final result. This often leads to different controversies between the seller and the customer that are centered around the variability of coal, the number of samples collected from a lot, the number of increments comprising each sample, and the mass of sample relative to the nominal top size.

The sampling of coal can take place from either stationary lots or from moving streams. Laboratory measurements of parameters in coal are very well established, but results can only be obtained twenty four hours after samples are taken. A fast, accurate, instantaneous method of determining the elemental composition of coal is important to the coal industry for pricing, quality control, and reduction of sulphur dioxide (SO2) emissions. In this regard, other techniques of analysis that are gaining prominence include x-ray fluorescence (XRF), (PGNAA) and (PFTNA). These are commercially available, on line analyser technologies that can also be coupled with a microwave moisture meter to monitor moisture.
Sampling coals from moving streams and stationary lots

Stopped belt
This method is recommended by international standards as a reference sampling method6. However, bias is introduced if the full range of particle sizes (large or small) is not represented in the sample. In order to eliminate such bias, an increment comprising the full width and thickness of the coal stream is extracted from a stopped belt at a point bearing a normal load. While the coal industry uses this as an ideal or reference method against which other methods may be checked, it is not practical as a standard sampling operation.

Falling stream
Sample increments, taken by a mechanical cross-stream cutter from the whole cross-section of a continuously moving stream at a transfer point, must operate safely and be capable of handling the resulting sample increment without undue physical strain5. The method is generally not used for transfer systems with a capacity of approximately 100 tons per hour or more. The cutter speed through the falling stream should be constant and not exceed 0.6 m/s7. The cutter aperture should be at least 3 times the nominal top size of the coal, with a minimum dimension of 30 mm and larger if necessary13. Any increments should never fill the ladle completely, and the cross-stream cutter must traverse the full cross-section of the stream.

Moving belt
Sampling from a moving belt is not recommended, but may be used to provide an indication of certain parameters of the coal.

Stockpiles
Building or reclaiming stockpiles provides the ideal opportunity to obtain representative samples. Regular extraction of increments using manual probes, augers or scoops, from the working face of the stockpile, from the bucket of a front-end loader, or from a single discrete load delivered to the stockpile before being pushed into the main stockpile can provide the best available sample, but this is clearly not a correct or representative sample. The aperture of the probe/auger or scoop ought to be at least 3 times the nominal top size of the coal, with a minimum dimension of 30 mm or larger, if necessary, to ensure that the increment never fills the scoop completely. Probes and augers must not be used for coals that require size analysis. Owing to the difficulty of insertion, a probe/auger ought only to be used for coals with a particle size of up to about 25 mm. Extraction of a full column of coal is considered to provide a representative increment.

Static Stockpiles
Sampling the outer surface of a stationary or static stockpiles is not recommended since the basic principle that each and every particle has the same probability of being in the sample cannot be upheld5. Results obtained from sampling static stockpiles are never correct nor representative and are merely indicative of the coal quality. Exposure, segregation and other causes mean that the surface layer on a coal stockpile is generally different in quality from the interior. Segregation of large lumps of coal around the toe and fringe of a stockpile occur during handling and must be accounted for when estimates of the particle size distribution results are made. In addition, the better air flows between the accumulated large lumps of coal accumulated around the bottom of the stockpile make these coals susceptible to spontaneous combustion. A more representative measure of particle sizes is obtained by covering the surface of the stockpile with an imaginary square grid and extracting increments from random positions within each square. Again, this is certainly not a representative or correct sample, but it provides the best available data given the dimensionality of the lot.

Grabs and front end loaders
At mining operations without appropriate sampling technology, extracting increments from the grabs or front-end loaders may be the only solution to the problem of sampling, but the sample can never be representative8. The operator of the grab or front-end loader is responsible for co-ordinating the extraction of the increments in an unbiased fashion. Manual probes, augers or scoops must be used to extract the samples as evenly spaced as possible over the surface of the front-end loader bucket or the grab. Such handling of coal results in accumulation of lumps at the bottom of large buckets. Dimensions of the coal lot can be reduced by random selection of grabs or front-end loaders that are discharged on to a clean surface, flattened and then sampled by either full depth or surface sampling. Sufficient grabs or front-end loaders of coal should be selected to ensure that the required number of increments can be obtained.

Barges, trucks, and railcars
Sampling of coals in barges, trucks, and railcars during loading or unloading is based on extracting increments from a number of evenly distributed points over the freshly exposed surface6. Sampling the tops of fully loaded barges, trucks or railcars before these are unloaded is not permitted, due to possible segregation or weather influences during transportation. Sampling the top surface of coal in barges, trucks or railcars immediately after these are loaded is permitted provided loading by layering of coals of different qualities did not take place. Coals transported in barges should be sampled at several points on sequential layers as the coal in the hold is exposed from time to time as the barge is loaded or unloaded. Failing to access all of the coal in the hold, may seriously bias the sample (ISO 13909-1 to 9:2001 (E) and ISO 1988:1975).

It is emphasised here that the different sampling procedures for stockpiles, static stockpiles, grabs, barges, and trucks are unable to produce an equiprobabilistic sample, i.e., a sample where all particles of the primary lot have an equal chance of being included in the sample6,9.

Mechanical sampling from moving streams
Details of the criteria and conditions that make for representative and correct sampling of moving streams of material have been investigated at length by Holmes and a group of co-workers at the CSIRO, Australia9. Coal is moved from the stockyard or unloading station on one or two parallel conveyor lines. Transport of coal in this manner transforms the three dimensional lot into a one dimension stream and provides conditions for correct increment delimitation, provided the stream is the same thickness and the cutter cuts the whole of the stream6. Sample increments are automatically cut from the coal stream at the transfer point prior to reaching the weigh belt.
sensor. Increments are collected at a primary sample position consisting of buckets moving with uniform speed across the falling coal stream. The primary samples are continuously prepared by crushing and dividing at three or four different stages. The final sample is dried and milled to 212-μm for chemical analysis. Samples for coal size determination are automatically supplied to the screens in tandem with the primary sample position.

Sampling is systematic and is either time-based (required increments taken at a pre-set time interval) or mass-based (required increments taken at a pre-set mass interval). Stratified random sampling extracts increments according to time or mass based on a random number (between zero and the sampling interval in seconds, minutes or tonnes) generator.

**Falling stream sample equipment**

Important design criteria for cross-stream cutters include the cutter velocity, cutter aperture and the angle of presentation of the cutter to the coal stream. These criteria are considered jointly because cutter velocities and the presentation of the cutter to the stream affect the effective cutter aperture presented to the particles in the stream. The design objective is to ensure that the mean trajectory of the particles in the stream is as close to normal to the plane of the cutter aperture as possible, to maximise the effective cutter aperture. The cutter velocity is particularly important in this regard because the particles in the stream intercept the cutter aperture at increasingly oblique angles as the cutter velocity increases, thereby reducing the effective cutter aperture. This places an upper limit on the acceptable cutter aperture. Examples of different types of falling stream sample equipment, according to ISO 13909-2: 2001 (E), are shown in Figures 1a to 1e.

**Cross-Belt Sample Cutters**

Two examples of cross-belt sample cutters are illustrated in Figures 2a and 2b. In both types, the sampling cutter pivots on an axis parallel to the centre-line of the belt. As the cutter traverses the full width of the belt in a rotary motion, the leading edges cut out the increment and the back plate pushes it off the belt. However, the two cutters differ considerably with regards to the movement of the cutter.
relative to the coal on the belt. The sample equipment shown in Figure 2a, has bearings on which the cutter shaft is fitted and fixed in place. In the case of the equipment shown in Figure 2b, the bearings are mounted on a trolley or sledge, which moves parallel to the belt and at a velocity equal to the belt velocity, during the sampling operation. In this way, the influence of the belt velocity on the cutter velocity relative to the coal is completely eliminated. However, such ideal sampling conditions are only achieved at the cost of a complicated and somewhat cumbersome sampling device. For sample equipment of the type shown in Figure 2a, the relationship between belt velocity and cutter velocity relative to the coal is important since the higher the cutter velocity is in relation to the belt velocity, the larger the effective aperture and the more favourable the sampling conditions will be. Furthermore, the higher the cutter velocity, the shorter the time will be during which the cutter, acting as a plough, will hold back the stream of coal.

For these reasons and because the density of the material to be sampled on a belt is considerably higher than that of material in a falling stream, the limitations on cutter velocities for cross-belt samples is less stringent than for those applying to falling-stream cutters. However, the use of high cutter velocities may result in an unacceptable degree of breakage of sized coal. In such circumstances, the cross-belt cutters may be used at a slower speed with the belt stopped, i.e. using it as a mechanical stopped-belt sampler. Irrespective of the cutter speed and aperture, cutters ought to be operated to minimise the bias.

Examples of cross-belt cutters according to ISO 13909-2: 2001 (E), are shown in Figures 2a and 2b.

**Location and operation of mechanical sample equipment**

The location of sampling equipment may vary depending on requirements. In order to uphold the principle of correct sampling, the sampling system must be located so that the entire lot is accessible, at the stage in the process where the measurements of quality and quantity are required. If variable flow rates result in increment masses which are unacceptably variable, a more uniform flow can be obtained by installing suitable surge hoppers with adjustable gates upstream of the sampling system.

The flexibility of sampling systems should be such that sampling equipment may be operated on a continuous or intermittent basis, the rate of increment extraction should be mass based, time based or stratified random sampling, and available increment extraction should be by mechanical falling stream or cross-belt methods. According to the ISO 13909-1 to 9:2001 (E) and ISO (1988, 1975) standards these options require the following procedures in order to be acceptable:

- The capacity of the primary sampling device, the size of the cutting aperture of the sampling device, the cutter velocity and the sampling interval should be checked.
- When the mechanical sampling installation is commissioned or when principal parts have been modified then, on completion of the procedures, tests to check for precision and bias should be carried out for the installation as a whole (see ISO 13909-7 and ISO 13909-8).
- Inspection and maintenance of the installation should be carried out daily prior to the start of each shift to ensure reliable operation within the established design and operating parameters.
- Coal build-up, blockages, restricted flows or suspected changes which may affect the sample, should be reported and corrected as quickly as possible.
- Upon completion of sampling a particular type of coal, the system should be completely cleared when a different grade of coal is to be sampled.
- A log book showing a record of inspections with details of breakdowns, blockages, etc., should be kept in an appropriate place. A record of the sample mass and tonnages to which it relates should be kept for each sub-lot.
- A mechanical sampling system should include lockable, adjustable controls to prevent unauthorised adjustment, an event recorder to indicate the number and/or frequency of increments taken during the sampling period, and remote indication that the sampling system is operating or stopped and that it requires attention.
- A check should be made to see that these functions are operating before commencement of loading each day.

**Eskom’s sampling practices at base load mines**

Payment for coal supplied to Power Stations (except for Hendrina Power Station) from base load mines is based on real-time analyses of calorific value (CV), ash (all elements), moisture, volatile matter and total sulphur. Daily samples are automatically collected by nominated representatives of the Power Stations, and a duplicate sample is analysed by the Colliery for quality control and quality assurance. Provided that the sample equipment is operational, well maintained, and bias free results are available every twenty-four hours from the laboratory. Well
established ISO method are applied, but analytical results may be subject to a dispute resolution procedure; as per the coal supply agreement, and a third party may be required to analyse the coal. Payment for the coal to Hendrina Power Station is based on the results of a sample stream elemental analyser.

For lower tonnages where flow rates do not exceed two thousand tons per hour, two stage sampling systems are used. Coal increments from the primary sample position are delivered via a belt feeder to a crusher where the nominal top size is reduced and a final reduction to the correct sample size is made. This final sample is held in a dust and moisture tight container, transported to the laboratory and analysed.

For higher tonnages, a three stage sampling system, which involves primary and secondary sample positions before crushing, is used. The two stage sub sampling, prior to crushing, reduces the amount of fines and associated coal handling problems at the sampling stations. A primary sample is extracted in accordance with the consignment standards, while a secondary sample event selects increments at a 6:1 ratio to provide the minimum increment mass. Coal from the secondary sample position is crushed and fed to a tertiary sample position where final division of the sample is accomplished.

### Online analysers

Currently coal management within Eskom, is based on the management of the coal supply agreement. However, principles that guide coal selection are dependent on the boiler requirements, economics, and emissions. Ideally, the cost of the coal should be minimal, the plant should operate at least-cost performance, and the plant performance should be maintained within environmental emission limits.

On-line analysers provide automatic, continuous, rapid and relatively accurate process data in real time. On line analysers enable feed forward control to be applied in the power plant to adjust feed rate, blends or other critical controllable parameters. Online analyses apply a wide range of technologies including nuclear, microwave, ultrasonic and optical to deliver an appropriate online solution. The instruments can be integrated into the plant control system and incorporate the latest web based control technology for remote administration and diagnosis.

### History of online analysers

Three types of online coal analysers were developed in the United States, Australia and Europe during the late 1970s and early 1980s. They included online moisture meters employing microwave technology, online ash gauges using gamma ray attenuation technology (collectively known as either dual gamma gauges, dual energy transmission (DUET), or low energy transmission (LET) gauges), or elemental analysers used for ash, sulphur, and sometimes ash constituent analyses. These analysers relied on prompt gamma neutron activation analysis (PGNAA) for elemental analysis, and they analysed sample streams rather than the full process flow. When PGNAA is combined with a moisture meter, as is generally the case, moisture, calorific value and sulphur can also be determined.

It should be noted that even with the use and application of on-line elemental analysers, that samples are collected from the mechanical sample equipment on a daily basis for the calibration of the on-line elemental analysers, and for the determination of abrasive index, size grading and hardgrove index performed in the laboratory.

On-line analysers provide a fast, accurate, instantaneous method of determining the elemental composition of coal for pricing, quality control, and reduction of SO₂ emissions. Elemental analyses include sulphur, silicon, aluminium, iron, calcium, sodium, magnesium, manganese, titanium potassium and chlorine. Some of the elements such as C, O, H, and S can be used for the elemental ash composition. Measurement of S is dictated by the control of SO₂ emissions from coal-fired power plants. Elements such as Na and Cl have harmful effects on boilers, causing fouling and slagging. Laboratory measurements of these parameters in coal are very well established, but results can only be obtained twenty four hours after samples are taken.

### Commercially available online analysers

On-line analysis technologies commercially available in the coal industry include:

- **Ash Monitors**: Dual gamma ash meters are widely used for the determination of ash percentages in coal.
- **Elemental Analysers**: Online bulk analysers deliver measurements of the elemental composition of bulk materials from either the conveyor belt or inside a vessel. The technique is relatively suitable for hostile, high temperature and high pressure environments. Neutron gamma analysers are used for simultaneous multi element analysis, independent of material segregation and changes in loading.
- **Moisture Analyser**: The low frequency microwave moisture analyser offers continuous, highly accurate on-belt analysis of bulk materials.
- **Ultrasonic Pulverised Coal (UltraPF) Mass Flow...**
The x-ray fluorescence (XRF) process control technology and its prototype was first developed in collaboration by Detroit Edison, Process Control Inc. (PCI) and the Electric Power Research Institute (EPRI). The XRF online analyser monitors ash, sulphur, calorific and a complete proximate analysis. It can be coupled with a microwave moisture meter to monitor moisture.

An x-ray tube is used to bombard the sample with incident radiation in the 3 to 20 KeV range. A silicon detector is used to measure the resulting fluorescent radiation. The electronics are sealed in a NEMA 4 enclosure with a thin window over the x-ray path to maintain a sealed environment. This eliminates the cesium source. In the past, detector technology limited the application of XRF technology. Sulphur was measured using low energy x-rays to excite sulphur (alpha) x-rays (2.31 keV) and detect low energy photons with a Ne/X gas filled proportional detector. The resolution was poor and the counters unreliable. Silicon photo iodide (Si PIN) detectors, which are electrically cooled, are now employed.

The coal is crushed to 95 mm passing or smaller, to provide a uniform surface to present to the analyser. The range of variability about the mean for variables analysed using XRF Coal Analysers and the standard laboratory analyses are shown in Table I.

The XRF Coal Analyser offers 95% of the features of a PGNAA analyser for significantly less money. The installed costs are less than one-half of the PGNAA system alone. The system requires no radioactive source, which increases reliability and safety with no special shielding.

The analyser calibration is independent of the coal seam.

Depending on application and measurement time, correlation accuracies achievable for PGNAA analysis of coal are:
- ± 0.1 weight % for sulfur
- ± 0.5 weight % for ash
- ± 150 Btu/lb (+ 0.349 MJ/kg) for heating value

(Source: Online Analysis of Heating Value, EPRI, Palo Alto, CA: 1999. TE-113817.)

<table>
<thead>
<tr>
<th>Elements</th>
<th>XRF coal analyser’s</th>
<th>Results from laboratory tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Sulphur</td>
<td>± 0.06% for sulphur (over a range from 0.68 to 1.23% on a dry coal basis)</td>
<td>± 0.23% for sulphur (over a range from 0.90 to 4.89%)</td>
</tr>
<tr>
<td>%Ash</td>
<td>± 0.30% for ash (coal ash was in a narrow range)</td>
<td>± 0.69% for ash (over a range of 5 - 65% ash)</td>
</tr>
<tr>
<td>%Moisture</td>
<td>± 0.80% for moisture (for a 15-25% range)</td>
<td></td>
</tr>
<tr>
<td>%CV</td>
<td>± 150 Btu/100% for CV</td>
<td>± 0.30% for iron (range of 5 - 6.5% iron)</td>
</tr>
</tbody>
</table>

(Online Analysis of Heating Value, EPRI, Palo Alto, CA: 1999. TE-113817.)
Pulsed fast and thermal neutron analyser (PFTNA)

A neutron generator based online coal analysis system referred to as the pulsed fast and thermal neutron analyser (PFTNA), capable of measuring the major and minor chemical elements contained in coal, utilizes nuclear reactions produced from fast and thermal neutrons, and isotopes with half-lives of seconds or minutes. The reactions at a nuclear level are illustrated in Figure 6. Characteristic gamma rays detected with bismuth germanate oxide (BGO) detectors are used for the identification of the various chemical elements. A key feature of the analyser is its ability to analyse automatically three distinct gamma ray spectra, and produce the elemental content of coal as it moves through a coal chute or conveyor. The main features of the analyser are self calibration independent of the coal seam, better accuracy in the determination of elements such as carbon, oxygen, and sodium, and diminished radiation risk.

PFTNA involves irradiating a stream of coal by a pulsed neutron generator, to produce 14 MeV neutrons in pulses several microseconds long and with a frequency of several kilohertz (kHz). Some of the fast neutrons are moderated by the material or moderators placed external to the material, thereby producing a field of thermal and epithermal neutrons for absorption by the material. Neutrons interacting with nuclei in the coal, results in the emission of gamma rays that have energies unique to each element. The millisecond pulsing of neutrons with a frequency of a few kHz allows the measurement of gamma-rays originating from neutron inelastic scattering, thermal neutron capture, and neutron activation. Three separate gamma ray spectra are acquired: one spectrum is acquired during the neutron burst (‘fast spectrum’) and two spectra are acquired in between the neutron bursts (‘thermal spectrum’ and ‘activation spectrum’). The fast high-energy neutrons interact with elements such as C and O emitting characteristic gamma rays. In between the neutron pulses, the fast neutrons within the coal bulk lose their energy through scattering with the light elements in the coal, initiating thermal neutron capture reactions. Such reactions measure elements such as H, S, and Cl through their characteristic gamma rays. For the measurement of Na, neutron activation is used, producing isotopes that have longer half lives (on the order of seconds) than the fast and thermal capture reactions. The gamma rays produced from
each category of nuclear reactions (fast neutron inelastic scattering, thermal neutron capture and neutron activation reactions) are acquired and stored in different spectra. By acquiring the gamma rays in three different time windows, there is a significant reduction of the background as compared with the spectra taken with a radioisotopic source.

A key feature of the analyser is its ability to analyse three distinct gamma-ray spectra, automatically and produce the elemental content of coal as it moves through a coal conveyor. The main features of the analyser are calibration, independent of the coal seam, better accuracy in the determination of elements such as carbon, oxygen, and sodium, and diminished radiation risk.

A laboratory investigation into the PFTNA technology, looked at 25 bituminous and sub-bituminous coal samples from various U.S. and Canadian coal seams. The results obtained showed weight percentage absolute errors of 2% for oxygen (range 5-40%), 0.18% for sulphur (range 0.2 - 4.0%) and 0.6% for carbon (range 42 - 88%). Note that these are much greater ranges than will normally be seen on a daily basis and that the error levels could be decreased if elemental ranges were smaller. (On-Line Analysis of Heating Value, EPRI, Palo Alto, CA: 1999, TE-113817.)

Cross belt online analysers and sample stream online analysers

Online stream analysers collect a primary sample of coal, discharged directly into the feed hopper on the analyser. The feed rate of coal through the analyser and the secondary sample position, is controlled by a variable speed belt that discharges the coal via a chute into the crusher. Crushed coal is discharged onto a secondary feeder belt and into a two way secondary sample device which allows samples to be collected from the belt into containers for laboratory analysis. The advantage of the sample stream analyser is that it has an optimal and constant cross-section for neutrons and gamma rays.

The cross belt elemental analysers are used for process control and sample stream elemental analysers for quality control. The cross belt elemental analysers are not the analytical equivalent, in terms of accuracy, of the sample stream elemental analysers, but they do carry many advantages such as little or no sampling requirement, lower cost and quicker installation and probably greater uptime. Field performance has shown these devices to be of adequate accuracy for many applications. Intelligently used and maintained, they offer the utility a cost-effective solution to many process challenges.

Cross belt online analysers analyse a variable belt loading and cross-section profile of coal on the conveyor belt. The advantages of the cross belt online analysers are several and include:

- With no additional supporting structure required installation time is dramatically less
- The analyser can be located where it is needed, not where there is a place for a sample system. There are no constraints on particle size, whereas the sample-stream analysers are usually limited to 3-4 inch topsize
- With their simple design, analysers are much easier to relocate if the mine conveyors have been moved, and
- The ease of maintenance means, although there are tunnel belt liners in cross-belt analysers, which occasionally needs replacement, there are no level sensors, belt drives, or input hopper parts that can wear and become subject to intermittent failure and replacement.

However, with all the advantages it should be noted that there are also some limitations associated with the Cross-belt Online Analysers that include:

- Accuracy of the cross-belt analyser is diminished relative to that of the sample-stream analyser owing to the variable and non-optimal physics of the coal on the conveyor and the need to subtract the varying effects of material in the belt itself
- Obtaining physical samples to calibrate and compare to the analyser is a challenge. Because of the size of the standards required, the use of reference blocks is also more difficult, particularly in wide belt applications, and
- The steel cable used in the manufacture of conveyor belts means that the high and varying iron content in the belt is not recommended with the use of the cross-belt analyser.

Choosing an analyser

The choice of analyser is amongst dual gamma ash (and moisture) gauges, cross belt sample stream elemental analysers, and sample stream elemental analysers. Criteria of greatest importance in choosing between dual gamma ash gauges and PGNAA elemental coal analysers include:

- Parameters of interest: If there is no need to measure sulphur on-line, a dual-gamma ash gauge may be adequate for the task
- Accuracy requirement: As the accuracy requirements become more stringent, the preference can shift from dual-gamma ash gauge to cross-belt elemental and ultimately, for the best accuracy possible, a sample-stream elemental analyser
- Coal complexity and coal quality variability: In multiple seam applications and in cases where the iron fraction in the ash is highly variable (more than 4% swings in Fe₂O₃), a dual gamma ash gauge is unlikely to perform acceptably.

Selecting appropriate technology

In choosing between the sample-stream analyser and the cross-belt analyser, the requirements of the analyses must be good for purpose, and related to the application of the results. For example, the greater the requirement for accuracy, the more favourable is the choice of the sample stream analyser. Although it is related to the quality requirement, sample stream analysers are more appropriate for load out situations where quality is paramount. Further upstream, where control decisions can be less exact, a cross belt analyser is often more appropriate. As a rule of thumb, it’s cross belt for process control, and sample stream for quality control.

Proximity to, or existence of, a sampling system will also
determine the appropriateness of the technology. The sample stream analyser is an appropriate technology if a complimentary sampling system is already available; where no proximal sample position is available, a cross belt analyser becomes relatively more attractive.

The relative permanence of the installation may be an important consideration. If it is known that the initial location of the analyser may be short-lived (e.g., two years) due to life of mine considerations, or planned changes in the coal handling scheme, the ease of relocation of a cross belt analyser might tip the scale in its favour.

Even though a sample-stream analyser might be more accurate and provide a shorter payback period to the buyer, there may be considerations that limit the available budget, and in terms of costs, the cross belt analyser may be a preferred option.

In choosing between the PGNAA and PFTNA technologies, the choice will usually include the objective of the installation, as well as pricing, quality control, and reduction of emissions (usually SO2). If the major elements (Si, Al, Fe, Ca, Ti and K), as well as ash, volatile matter and calorific value are important then a PGNAA instrument may be sufficient. If the online coal analyser should be capable of measuring the major and minor chemical elements (Na, Cl, C, O) then PFTNA is the more suitable option; Na, Cl and C can be measured by PGNAA only if their concentration in coal is quite high.

The source of neutrons for irradiating the material will depend on the range of energies of neutrons for analytical purposes. The gamma rays produced from a wide energy range opens up many reaction channels such as fast neutron inelastic scattering, thermal neutron capture, and neutron activation reactions, allowing for a wider range of elements to be determined at lower concentrations with higher sensitivity. The lifetime of the source together with compactness, portability and the ability to turn off or safely store the source when not in use, must be considered. The radiation hazards are much less severe for neutron generators. Unlike a 252Cf source, neutron generators do not produce neutrons until they are energised. This greatly reduces the shielding requirements of the source, because it only needs to be shielded when in operation. Personnel can be protected by simply placing them a sufficient distance away. When the neutron generator tube needs replacement, a new one can be shipped by a common carrier without being protected by simply placing them a sufficient distance away. When the neutron generator tube needs replacement, a new one can be shipped by a common carrier without special shielding requirements. When the (d-T) generator is not used, the only radiation hazard is from the tritium beta source that decays with a definite half-life (about 2½ years) whether it is used or not.

Only two detector categories namely, inorganic scintillators, (NaI(Tl) and BGO are popular), and germanium semi conductor detectors are presently available for the detection of gamma ray energies of several hundred keV. The choice of detectors is a trade-off between counting efficiency and energy resolution. Scintillator detectors have a greater efficiency, larger photo fraction and lower cost of and are preferred if a measurement of the intensity rather than accurate energy determination is the prime objective. The light yield should be proportional to the deposited energy over a wide range as possible. The energy resolution of scintillators is relatively poor. Background radiation levels dictates limits of detectability. Detectors operated in pulse mode, collect an individual quantum of energy detected as a distinct pulse, increasing sensitivity.

**Analyser Location**

The analyser should be located as close as possible to the point where the coal composition has its highest value. Two primary factors tend to govern the choice of location. If the coal is sorted, the analyser should be located close to, but obviously upstream of, the sorting point. A coal complex consisting of numerous coal flow paths may need more than one analyser with the preferred sites determined by the greatest variability in coal quality. In a blending application, the analyser is preferred immediately downstream of the point at which all the coal streams come together. Unfortunately, the ideal process location is often unavailable because of the second key factor namely, physical or environmental constraints.

Such constraints may include factors such as the lack of a sampling system (to either feed the analyser or to be able to obtain occasional physical samples for analyser comparison purposes), lack of headroom or horizontal space limitations, inconvenience of running utilities, and inadequate protection from the elements. As a result, the choice of an analyser location is often compromised.

In choosing the right vendor for such technologies it is important to consider aspects such as maximising the performance, reliability, ability to deliver total system solutions, equipment and installation safety, and continuous improvement and innovation.

**Conclusion**

Significant value added is evident as a result of the installation of process control analysers. These include a number of benefits including the reduction of forced outages at the plant by controlling the ash fusion temperature of the coal, thereby the availability of the Power Station improves. The use of the analyser for precise blending control is an important innovation in that minute by minute data from the analyser allows the plant to supply more consistent coal blends to the units and allows the plant to maximise the ash softening temperature of the blend, while reducing the need for more expensive, high fusion coals. When the analyser is used as a tool to control coal quality, for more reliable coal blends, it enables the Power Station to effectively burn coals from a variety of sources. The online analyser allows the plant to closely monitor the quality of the coal being delivered to the plant by their coal suppliers and the consistency of the delivered coal can be monitored. The online analyser also allows for quicker identification and correction of equipment problems in the plant. In the past, plant operational problems were often blamed on coal 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. (Hunter Coal Gen Paper, Snider, K. Evans, M., Woodward, R. C., PacifiCorp, Thermo Electron Corporation, Using An On-line Elemental Analyser For Improved Boiler Efficiency, (2001))

The results of laboratory analyses are well established and conducted according to IS0 standards, however, results may not be available for many hours after the testing. Other disadvantages of off-line testing are that the samples taken may not be representative of the process flow and the testing may be relatively expensive and are labour intensive. Online XRF analysers can perform elemental analysis (includes ash
content, S, and calorific value – complete proximate analysis), PGNAA analysers produces a more complete elemental analysis (includes ash content, calorific value and major elements in coal, sulphur, silicon, aluminum, iron, calcium, titanium and potassium and, if the percentage in coal is high enough, sodium) and PFTNA analysers provide most complete elemental analysis (includes ash content, calorific value and major elements - sulphur, silicon, aluminum, iron, calcium, titanium and potassium and better accuracy in the determination of elements such as carbon, oxygen, and sodium contained in coal). XRF is less expensive than PGNAA, does not use a radioactive source, and, although, it provides less information than PGNAA, it provides sufficient information to calculate heating value to reasonable accuracies. The disadvantages of the XRF technology, are: it is less precise than PGNAA, it does not provide full elemental analysis, it is limited to coal sizes less than 10 mm and, therefore, the coal must be crushed, and it measures surface composition, which may be a problem if there is significant vertical segregation of the coal flow. PFTNA comparable in cost to PGNAA, be a problem if there is significant vertical segregation of crushed, and it measures surface composition, which may offer some operating advantages along with the ability to improve the accuracy of the measurement of C and O. Moisture content measurement is routinely measured with proven commercial instrumentation. Measurement of moisture content will be required with either ash measurement or elemental analysis in order to calculate heating value. Microwave attenuation and phase shift represent the dominant technology. On-line analysers will require careful calibration. For most technologies, the samples used for calibration need to be representative of the range of coals that are to be measured online. Most of the ash determination and elemental determination systems rely on the use of radioactive sources. In such cases, safety is paramount and all manufacturers have carefully designed features to reduce radiation levels to acceptable levels. Due to the decay in the source, the life of the source (typically, in the order of a few years, should be considered in evaluating the life cycle cost of a particular system.

References

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2000-2004 Eskom Enterprises – Technology Services International: Senior Technician:
Duties included supervising the water laboratory and then the coal & X-ray laboratory, training, safety, quality (implementing and ensuring accreditation procedures are in place), project management (unit charge management), testing, investigating and researching services in advanced analytical techniques, customer liaison. Gained experience in analysing alloying elements in metals, coal (XRF) and minerals and asbestos analyses (XRD).
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2004- present Generation Primary Energy Coal: Coal Quality and Quantity Auditor:
Coal quality auditor
Manage the structuring, coordination and implementation of all technical aspects of coal quality and quantity management related matters associated with the respective coal contracts.
Assist in defining the quality and quantity measurement procedures for coal contracts.
Audit adherence to quality and quantity management procedures.
Develop and inspect sampling processes.
Participate in ISO standards committees

SAMPLING, SAMPLE PREPARATION AND ANALYTICAL PRACTICES