COAL QUALITY CONTROL

Source: Aker Solutions

DANIEL MAHR, P.E OF US BASED ENERGY ASSOCIATES, P.C, GIVES US AN IN DEPTH LOOK AT THE MAJOR ISSUES RELATING TO COAL QUALITY FROM THE PERSPECTIVE OF THERMAL POWER GENERATION.

The power industry is confronting challenges with seemingly conflicting goals – affordable rates, dependable service, and reduced impacts. Different energy conversion technologies have their applications, but no single option does it all. Wind, solar, and hydro options don't use any fuel, so shouldn't we just rely on these technologies? Wind power is best sited where the duration/velocity makes sense, away from migration pathways, and away from neighbours who would object to noise and fluttering shadows. It will likely require 100 per cent back-up or additional energy storage systems, and new longer transmission lines to load centres are often required. There are similar requirements for solar power, just substitute lumens for velocity. With hydro power, there are concerns for fish migration/spawning, land use, geological concerns for

"As power plants face a growing need to reduce costs and environmental impacts, coal quality is increasingly an issue of interest, as a means to do more with less.."

supporting the weight of a new lake, stability concerns for newly saturated perimeter hills that can result in landslides, and the impact of a drought on production. Its the delivered cost on your utility bill that counts; the capital cost of the plant itself is only a single component.

Large, central power plants provide the reliability and flexibility utilities require for baseload, cycling, and on-demand situations. They can be strategically located near load centres or along transmission corridors and provide the economy of scale needed to minimize the cost of production.

The single, largest, operating cost for a gas, oil, or coal -fired electrical power generating station is fuel. In the simplest terms, the power plant is converting the chemical energy stored in fuel to electrical energy. Plant design, process requirements, and efficiency goals make fuel quality an issue. A high performance engine needs a high quality fuel.

So as we see, when we purchase a fuel, we are purchasing energy value. Coal is the most difficult to extract and burn, but as a source of energy, it is also the most economical. That's the reason it fueled the industrial revolution and has historically been the fuel of choice in many countries for power generation. It continues to be the fuel of choice for new power generation for counties with high growth, India and China for instance.

What's Coal?

Coal is formed from organic plant matter. It is the stored product of the photosynthesis

of solar energy that has transformed carbon dioxide and water molecules into compounds containing carbon, hydrogen, and oxygen. Coal is created over aeons with favourable geologic and climate conditions. The results for each individual deposit is time and process dependent, so coal properties vary from region to region, mine to mine, and even seam to seam. Parameters such as heating value, moisture content, sulphur content, ash composition, and ash quantity are important in maintaining boiler rating, reliability, and performance. The absorption of nutrients by plants and the geological sediments/ conditions introduce non-combustible minerals to coal, which for combustion purposes are impurities. The combustion residue of this mineral matter is ash.

Combustion Technology Issues

As power plants face a growing need to reduce costs and environmental impacts, coal quality is increasingly an issue of interest, as a means to do more with less. Coal quality affects plant performance in efficiency, emissions, and availability. At high combustion temperatures, fractions of ash can become partially fused and sticky. Depending upon a particular coal's ash fusion temperature, it can adhere to heating surfaces building up as slag on water-walls and bridging tubes to obstruct the flow of combustion gases. Tube/refractory erosion and corrosion are issues too.

Recognizing the importance of fuel quality, coal specifications have become more restrictive, monitoring more intensive, and penalties more expensive. This can lead to

increasing fuel cost as the demand for the most desirable sources escalates.

For large, central power stations, pulverized coal-fired (PC) boilers have evolved as the technology of choice. PC boilers combust a suspension of finely ground coal that is blown into the furnace in a gaseous matrix to form a large, stable flame vortex. Fine coal particles react similarly to atomized particles of liquid fuels. The reaction time is measured in seconds. The amount of coal, its heating value, and the impurities determine the size and design of the furnace/boiler and placement of the heating surfaces. Coal ash/impurities can form deposits on heat transfer surfaces and the ash itself must be collected. Products of combustion including SO_X and NO_X compounds must be controlled. The amount of ash and its constituents are basic design parameters for the boiler and the back-end air quality control systems.

Circulating fluidized bed (CFB) boilers are a more recent design option. Their size has gradually increased since the technology was first commercially demonstrated at the Nucla Station, in an EPRI (Electrical Power Research Institute) sponsored program. In a CFB boiler, fuel is combusted at lower temperatures in an aerated/fluidized bed of material that typically includes crushed limestone. The lower combustion temperatures and calcium content of the limestone reduce the formation/discharge of SO_X and NO_X compounds, so emission controls start in the combustion zone. Air quality control systems can further reduce

emissions. The relatively long residence time for fuel within the combustion zone makes this combustion technology useful for lower quality fuels – fuels that are difficult to ignite, take longer to fully combust, and contain large quantities of impurities that are problematic for suspension firing in a PC boiler.

Other combustion technologies, like coal gasification and pressurized fluidized bed boilers are being developed/demonstrated. The co-firing of coal with biomass and other solid fuels is also practical. Each technology has its own, unique requirements.

So while coal quality control is an issue of importance, its means and methodology cannot be separated from its utilization. Combustion technology and fuel quality are coalescent issues.

Resource Management

Coal quality control begins at the mine. The mining engineer is responsible for developing the mining plan, monitoring production, and managing operations. One objective of any mining plan is to maximize recovery of the deposit of suitable quality coal. This is an economic issue; it's cost effective to retrieve as much of a given resource that is economically possible. Mine development has sunk costs that should be "spread" over as much coal as possible. There are economic "cut-off" parameters that impact the mine plan. For open cast mines, the issues include strip ratios, how much overburden or interburden must be removed to expose a given quantity contained in a coal seam. For underground

mines, it can be the seam height, pitch, depth, roof stability, etc.

Mine plans recognize the spatial attributes of coal quality, some seams will be better than others. As a result, the plan will typically manage mining areas to balance coal quality. Mining only the highest quality seams at the outset will truncate the life of the mine. Coal quality for any given mine can also change over time, as lower seams are used or new areas exposed. Long-term relationships with a mine should recognize how quality can change and continue to be vigilant, rather than complacent.

Coal Preparation

The purpose of coal preparation is to improve the quality of coal by cleaning to remove inorganic impurities and sizing for handling, process, and combustion requirements. The relative density, friability, hardness, and strength of different elements within the coal matrix are key parameters for mechanical cleaning processes. The specific gravity of coal ranges from 1.23 to 1.72, depending on rank, moisture, and ash content. Mineral impurities have higher densities and this property is employed by a variety of separation methodologies. A coal preparation plant typically contains different circuits delineated by particle size. The larger particle fraction from 6 to 18mm will normally contain coarse rock that can be separated by a vibrating jig or dense medium bath. For the smallest particles, those that are <0.5mm, froth flotation is used. In this process, a conditioned feed pulp is introduced onto

the top of the froth bed. Hydrophobic coal particles attach to rising bubbles and stay in the froth while hydrophilic mineral particles pass through it and discharge at the bottom of the floatation cell. Cyclones are used and the lighter coal particles swirl upward to a clean coal discharge while higher density impurities sink to the funnel outlet. Various dewatering screens, thickeners, and filters are used to separate the product and recover the medium.

Coal preparation plants operate at a given level of efficiency, depending upon the processes employed and coal properties. Lower rank coals are particularly difficult to clean by traditional methods.

The cost of cleaned coal is more than the mined product for two reasons. First, there is obviously a capital and operating cost associated with the process. Secondly, the efficiency of the coal preparation process means that some of the energy value reports to the "refuse" or "tailings" rather than the marketable "product". As coal preparation technology has advanced, so too has the efficiency of the process. Older plants discarded much more energy with the refuse than they do today. This fact and the advancement of CFB technology has resulted in an economic environmental clean-up circumstance. Large tailing accumulations that were discarded over decades near older coal preparation plants are being reclaimed as the primary fuel for some CFB boilers.

Coal specifications vary with user requirements. The most successful coal preparation plants are adept at meeting these

"In theory, bed blending provides a reliable, repeatable methodology to reduce the variability of raw materials. "

purchase requirements, with relatively small margins of error. There is no single product specification that applies to all users; although there are generally recognized requirements that can be considered "world class" coal products, which are suitable for many PC boilers in coal import countries. Coal export countries have adapted to technology advances by producing "world class" fuel for export and a lower quality product for local plants. The objectives are to increase the marketability and sales of indigenous resources while avoid discarding energy in refuse piles. There are economic/utilization reasons for establishing different export and local quality parameters.

Coal Blending

Premium fuels usually have premium prices. It's true for our cars and true for our power plants. A prime objective for any fuel buyer is to negotiate a better deal. Fuel quality then becomes an issue; what's acceptable? Many car drivers bypass expensive gas stations and opt for a lower octane fuel, if their cars run fine with it.

Blending provides a tool to more closely match coal quality to user requirements. Depending upon the objectives, blending can be employed to: 1) reduce fuel variability or 2) combine different raw coals into a useful fuel product. Coal blending is being used by a growing number of utilities to gain more control of fuel characteristics while maintaining or reducing fuel cost.

There are two types of blending that can be used, bed and belt blending.

Table 1: Blending techniques	Bed	Belt
Extend mining reserves	X	X
Minimize selective mining	X	
Combine dissimilar coals		X
Reduce fuel variability	X	
Produce prescription fuel products		X

Bed blending is a technique used by process industries to convert heterogeneous raw materials into a stable homogenous product, which is important to optimising plant performance and controlling product quality. It is used to reduce the random variability of raw materials by implementing stockpile management techniques. It can be advantageous for mine-mouth plants whose coal deposits have wide variations of heating value and other properties.

Belt blending is a second methodology and one that is most widely used by power plants. In this stockpile management technique, distinctly different receipts from known sources are stacked in segregated stockpiles. Combinations of stockpiles are reclaimed at predetermine rates to a recipe

that best meets plant requirements. The recipe will normally consider heating value, total ash, sulphur content, and other elements like iron, sodium, etc. that affect its acceptability for some boiler designs. For sure, the recipe will consider fuel price on an energy basis, US$/MMBtu or €/MJ.

As illustrated in Table 1, Belt and bed blending techniques are suitable for a number of different situations:

Blending is useful in a number of phases of coal extraction, preparation, and utilization. It has been particularly popular at some plants to address changing environmental requirements in a manner that meets reliability parameters for boiler operation while minimizing the cost impact to customers. This is the case in the US
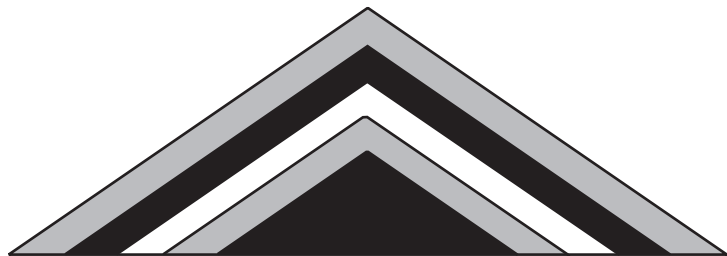
Figure 1: Chevron stockpile cross-section for bed blending

where numerous plants which have blended different coals to meet emission requirements for SO_x, increase heating value to meet full load requirements, after switching to a subbituminous coal, or to mitigate problems associated with the iron or sodium content.

Bed Blending

Figure 1 illustrates the chevron/windrow method for bed blending. Coal is sequentially layered by a travelling, linear stacker. Each subsequent layer completely covers the previous layer, thus forming a chevron cross section. If the traverse speed of the stacker is fixed, successive layers become thinner as they "cover" a larger cross section surface area, i.e. each layer has the same volume as controlled by the stacking rate and the traverse speed of the stacker. If large lumps are present, these will roll down the sloped surface of the stockpile and collect at the base, while smaller particles and fines tend to accumulate in the centre of the cross section. When this segregation is problematic, other stacking/reclaim methodologies can be used.

The design of the reclaimer is important for bed blending. The objective is to reclaim the cross section of the stockpile, to "slice" a section of the windrow from toe-to-toe of the stockpile. In this manner, multiple layers are simultaneously reclaimed, from the base of the stockpile to its surface. The variability of all layers is thereby blended by each reclaim slice of the cross section. Like a layer cake, each slice reclaims some of the filling, frosting, and cake. Each slice contains elements from the first layer to the last. As
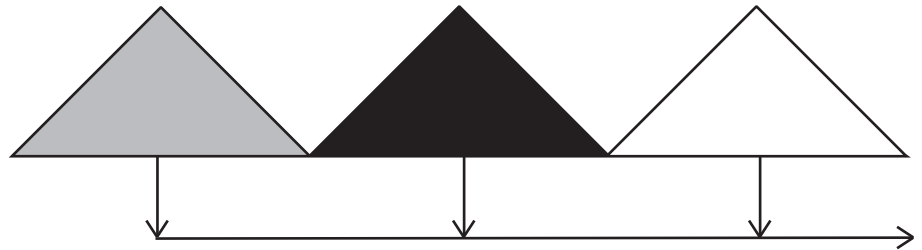

Figure 2: individual/unique stockpiles are simultaneously reclaimed in belt blending

a result, while the properties of each layer can vary significantly, the properties of each slice closely resemble the mean value of the stockpile. Wild hourly swings are blended into weekly averages. The number of layers is of statistical importance. The following equation for the standard deviation of a sample illustrates the concept.

$$S = \sqrt{\frac{\sum (X - \overline{X})^2}{N-1}}$$

Where: S = the standard deviation
X = each value in the sample
$\overline{X}$ = the mean of the values
N = the number of values

The fully formed, layered, window stockpile is a representative sample of the entire mine product. As the number of layers in the stockpile increases, the standard deviation from the mean decreases. So stacking lots of layers is a preferred methodology.

In theory, bed blending provides a reliable, repeatable methodology to reduce the variability of raw materials. At the Four Corners Plant, due to geological circumstances, the Navajo Mine's coal reserves vary from less than 7000 to approximately 10,200 Btu/lb. Because of the bed blending

system, the plant was able to deliver an average blended product of 9000 +/- 47 Btu/lb. fuel to the boilers. Mining is not a random operation, so the operators are cognizant of what's going into the bed blending pile and the average can be tweaked to stay within the limits. What the bed blending piles do is blend the too good with the too bad into an acceptable, uniform product.

Belt Blending

Figure 2 illustrates belt blending technology for quality control. Belt blending combines the characteristics of two or more different grades of coal. Each grade is individually stockpiled and physically segregated. During reclaim, these stockpiles are proportionally combined most commonly by either volume or weight. Weight is the more accurate method since precise weigh feeders, weigh bins, or belt scales can be used to automatically monitor and control the output of reclaim feeders. Conventional sample systems are then employed to monitor input/output of the bed blending system.

In belt blending, grades of coal can be combined on the basis of a number of characteristics. This can be energy value, percent ash, sulphur content, amount of

sodium, etc. For characteristics "X", the following equation can be used to calculate proportional blending:

$$Xb = \sum_{i=1}^{n} \sigma i \, Xi$$

$$= \sigma 1 \, X1 + \sigma 2 \, X2 + \sigma 3 \, X3 + \dots + \sigma n \, Xn$$

where:
X = the value being controlled
σ = the proportional amount of each component
i = a suffix to indicate the particular component being controlled
1, 2, 3, ...n = various specific components or parameters being blended
b = the blended product

This equation assumes that the mean values of each component is known and constant. As such, it is a simplification of what can be expected from grades of coal that are at least somewhat variable. For precise applications, the quality of each stockpile can be tracked and its average adjusted. Some power plants will manage their stockpiles by individually stacking each shipment of coal. That can require a large stockpile area.

While the mathematics may appear to be relatively simple and straight forward, that is not always the case. Ash softening temperature is a property that is important to furnace slagging. It depends upon the nature, amount, and relative percentages of certain minerals – particularly iron, calcium, and magnesium. Eutectics come into play so a blend of two coals can result in an ash

softening temperature that is lower than either, individual coal. It is similar to what occurs with adding antifreeze conditioner to water in a car's radiator. The -34°C freezing temperature for 50/50 blend of ethylene glycol and water is lower than either component. Laboratory testing and test burns before making a long-term commitment can be important when selecting a new coal for blending.

On-line Analysis

Most belt blending systems rely on conventional belt scales and sampling systems. Belt scales provide real-time control of the proportional reclaim rate from each stockpile. The laboratory analysis of collected samples reports the results of input/output quality. Laboratory reports are not available until after-the-fact. This delay in discovering the quality of the blended product can be problematic, when things just start to go wrong or when the input is erratic/variable.

The most direct method of controlling the coal blending process is an on-line nuclear coal analyser. These analysers utilize gamma radiation to determine the elemental composition of coal. On-line nuclear coal analysers provide fast, accurate, real-time information concerning the elemental composition of coal including identification of sulphur, carbon, oxygen, and hydrogen. In addition, these analysers can measure moisture and ash content. Based on the measured constituents, the analyser includes software to determine the heating value (Btu/lb) of the coal. As a result, on-line

nuclear coal analysers have the potential to optimise the sulphur content and the heating value of the coal blend, with corresponding environmental and economic advantages for the operating plant.

Poor lignite fuel quality plagued the 440MW, mine-mouth, CFB, Red Hills Power Plant located in northern Mississippi, USA. On the coal quality scale, lignite is a younger, lower heating value product than the bituminous coal that internationally marketed. The Red Hill's mine has relatively thin, variable lignite seams that are separated by thick interburden parting layers. The complexity of the lignite formations and an annual 52 inch rainfall are mining challenges. A combination of truck-shovel, dozer, and dragline are used to remove the parting layers.

The percent ash was evaluated as a primary indicator for boiler problems. While 23.5 per cent ash was originally established as the upper operating limit, once commercial operations began the practical upper limit was discovered to be 18 per cent, to avoid combustion problems. Both the mine and the power plant experienced financial distress due to coal quality issues. The plant was experiencing forced outages and "derated" operating periods while the mine was subjected to the rejection of coal deliveries.

At the Red Hills Plant, coal is stored in two Eurosilos. One silo is now filled with lignite having an ash content of 15 per cent or less. The second silo is filled with lignite having ash that is 15 to 20 per cent. Three on-line analysers were retrofitted to the coal handling system. One controls the input to

> " Laboratory testing and test burns before making a long-term commitment can be important when selecting a new coal for blending."

the Eurosilos. The other two analysers control the belt blending reclaim system. With this retrofit, the mine and plant have learned how to coordinate their actions to ensure the quality of coal that is conveyed to the plant's boiler silos meets the plant's operating requirements.

The US$2.0bn Longview Power Plant is a 695MW supercritical PC plant being constructed in Maidsville, West Virginia. It will be one of the cleanest, most efficient solid-fuel power plants in the US, with

advanced combustion control technologies, when it begins operating in 2011. This is a mine-mouth plant from which coal is delivered by a five-mile, overland conveyor system. Adjacent to Longview is a coal preparation plant and coal blending yard. The mine-mouth coal can be diverted to these facilities and/or directly routed to Longview's receiving conveyor, which is fitted with an on-line coal analyser.

The on-line coal analyser on Longview's coal receiving conveyor will give the plant

and the blending yard real-time readings of coal quality being delivered to the plant. The delivered coal can either be stacked into the plant's stockpile or directly conveyed to Longview's boiler silos. Bypassing the plant stockpile should be an efficient mode of operation but it makes the quality of the coal receipts of immediate importance. Blending will be done at the adjacent Blending Yard, not at the Longview Power Plant.

The design system provides the flexibility to mix-and-match what's delivered to Longview. While most of the coal will be supplied from a local mine, a variety of products handled and stored at the Blending Yard can be blended with the mine-mouth coal. Via a wireless network, the coal analyser will communicate coal quality data to mobile equipment reclaim operators in the Blending Yard. They will be able to alter/adjust their reclaim activities to best meet coal quality requirements.

Quality Control

So as we see, there are different flavours of coal, different tastes in boilers, and different reasons to select one recipe or technology instead of another. Coal is an economical source of energy and controlling coal quality is a way to do more with less. ■

For more information on this topic or if you are interested in Energy Associates and its expertise in this arena, consider visiting the company's website (www. www.energy-pc.com) or contacting the author via email at: DanMahr@Energy-PC.com.

The 696MW Longview power plant, situated in Maidsville, West Virginia makes extensive use of an on-line coal analyser in order to insure that blending operations are as effective as possible. Source: Aker Solutions.