SUITABLE AND SAFE SAMPLING

Collecting coal samples can be accomplished in a variety of ways – some less than ideal. **Paul Reagan, Sampling Associates International, USA,** examines the relative effectiveness of the various methods and the specific limitations of coal sampling, as well as introducing a new sampling device that may be useful in certain situations.

In many commercial coal sales transactions, the contractual language addressing the sampling method simply states that the samples will be taken "in accordance with ASTM (or ISO) standards", without any additional specificity. It is one objective of this article to inform the reader that this is a mistake: understanding the effectiveness of the various sample collection methods is crucial to clarifying what method is to be used in the contract language. Both ASTM and ISO have a number of different sampling methods and, without specifying, either party can select an inferior method and still be in compliance.

ASTM and ISO have standards addressing both mechanical and manual sampling of coal. Mechanical sampling is addressed by ISO 13909 and ASTM D 7430. Manual sampling is addressed by ISO 18283 and several different standards in ASTM. One is manual sampling using part-stream sampling (D 6609); the other is stationary sampling in railcars, barges or stockpiles (D 6883). Thus, any of the manual methods in these standards could be used and still be "in accordance with ASTM (or ISO) standards".

Ranking the sampling methods

Below are the details and ranking of these various sample collection methods, which will allow the user to better select the method they actually require for their transaction.

In ASTM Standard D 2234, the standard practice for the collection of a gross sample of coal, the sampling methods are ranked from best to worst in accordance with their condition. ISO standards are in close agreement with this. They are as follows:

- Condition A: stopped-belt cut sampling.
- Condition B: full-stream cut sampling.
- Condition C: part-stream cut sampling.
- Condition D: stationary sampling.

The key to understanding why condition A is the best method and condition D is the worst method is that many of the coal characteristics that are commercially relevant (moisture, ash, calorific value, etc.) are not distributed equally in the different size fractions in the consignment.

A simple, but important, example of this is shown in Figure 1. This shows a sample from a barge of coal from a single mine, which is first screened into its various size fragments and then analysed for dry ash. The resulting distribution of ash in the different size fractions is very typical, with lower ash in the larger pieces and higher ash in the smaller pieces. Many coals have wider ranges compared to the example here. Ash content and calorific content are inversely proportional; as the ash rises the calories fall.

Moisture content is directly related to surface area, therefore the same effect is seen in percent moisture with the fine coal having much higher moisture content than the larger pieces. These two distributions of

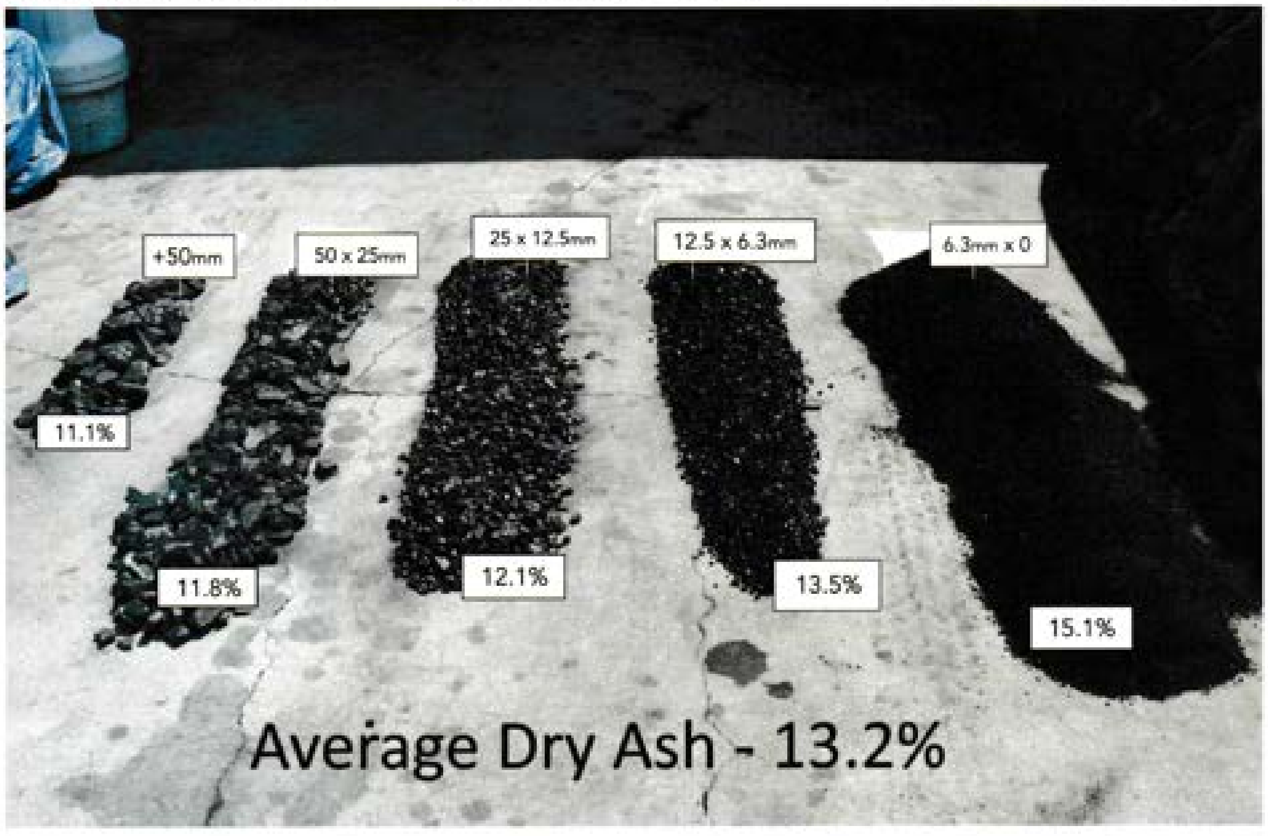

Figure 1. The ash content changes with different sized particles.

high ash and high moisture in the fines have a compounding effect on one of the most important commercial issues: as-received calorific value.

Due to this disproportional distribution of important characteristics in the different size fractions – true for most bulk materials – the true objective of any sampling method is to capture the same size distribution in the consignment in the gross sample (before any crushing or dividing). Failure to do so will produce a test result that is biased towards the characteristics in the size fragment that is over represented.

The preceding four sampling conditions are ranked from best to worst on their effectiveness in accurately capturing – in the sample – the size distribution of the cargo.

Probability versus judgment sampling

The other key to understanding this ranking is that cargos of coal segregate by particle size whenever they are handled. It is common to see particle size segregation when coal is being stacked into a stockpile with the large pieces rolling down the sides to the base. However, there is quite a bit of segregation that is not as visible to the human eye, which takes place while coal is on a conveyor belt rolling over idlers or passing through transfer points.

In order to ensure that the sample collection method can accurately capture the particle size distribution in the consignment, one fundamental rule must be met: all parts of the fuel (coal) in the lot shall be accessible to the sampling instrument and parts of equal mass shall have an equal probability of being selected and included in the sample.

This fundamental requirement has two parts. The first part is that since all of the fuel (coal) in the lot shall be accessible to the sampling instrument, the sampling must take place as the cargo is moved from one location to another. The second part is that since all the particles of equal mass must have an equal chance of being selected for the sample, the sampling method must have the ability to overcome the natural size segregation that occurs when coal is handled.

Those sampling methods that meet these requirements are called probability samples. Those that do not are called judgment samples.

In effect, condition A (stopped-belt sampling) and condition B (full-stream sampling) satisfy these two requirements and are thus probability samples. They both take place as the consignment is moved by conveyor belt so every particle in the consignment is accessible to the sampling instrument and has a chance to be selected for the sample. In addition, they both have the ability to overcome the natural size segregation that occurs when the coal is handled because they both take a full-stream increment, which means they capture the correct particle size distribution even when it is segregated.

In condition C (part-stream sampling) and condition D (stationary sampling), neither of these two requirements can be met. In both of these sampling methods, large parts of the consignment have absolutely no chance of being selected for the sample. And neither method is able to overcome any segregation that does occur because that can only be done with a full-stream cut. As such, both of these methods are judgment samples.

The reason that condition C is ranked higher than condition D is that condition C takes place when the coal is being moved on a conveyor. This means that much more of the consignment is accessible to the sampling instrument; therefore the

Figure 2. Installation of a Mechanical Part-steam Sampler (MPS).

Figure 3. The MPS includes double sample scoops (Note: during operation, they alternate via a timer).

chance of that sample being representative is higher.

ASTM has one standard for stationary sampling, which covers the sampling of barges, railcars (wagons) and stockpiles. The sampling of railcars is preferred to barges, and barges preferred to stockpiles. The commonsense reason for this is that a larger proportion of the consignment is accessible to the sampling instrument (because the tonnage in railcars is smaller than in barges, which, in turn, are usually smaller than stockpiles).

However, it is important to remember that it is not just the size distribution that is important, but also the moisture distribution. Moisture in stationary coal almost always migrates to the bottom of the stockpile, barge or railcar. In addition, there are frequent moisture changes right at the top surface layer (drying or precipitation). Stationary sampling cannot usually reach much past the surface of consignment and so it is very difficult for even the most experienced and diligent sampler to overcome these challenges.

One important comment on judgment sampling is that, in most cases, the samples are collected manually, which introduces another risk element. Both ASTM and ISO standards recognise the human element in sampling and ranks those methods without the human element higher than those with. There are many excellent manual sampling technicians, but ultimately they are exercising their judgment on which particles from the consignment get into the sample.

Table 1. Comparison on blended coal – dry basis results

Method	Moisture	Volatile	Ash	Sulfur	BTU	Calories
Mech.	7.62	35.17	14.21	0.87	12 688	7049
MPS	7.12	35.27	14.50	0.84	12 652	7029
Method	Moisture	Volatile	Ash	Sulfur	BTU	Calories
Mech.	7.68	34.23	14.08	0.85	12 663	7035
MPS	8.14	34.89	14.19	0.85	12 639	7022
Method	Moisture	Volatile	Ash	Sulfur	BTU	Calories
Mech.	7.52	33.30	15.11	0.86	12 631	7017
MPS	7.78	33.91	14.61	0.87	12 688	7049

Table 2. Comparison on petroleum coke – dry basis results

Method	Moisture	Volatile	Ash	Sulfur	BTU	Calories
Mech.	7.53	10.72	0.51	5.59	15 242	8468
MPS	7.91	10.52	0.47	5.60	15 276	8487
Method	Moisture	Volatile	Ash	Sulfur	BTU	Calories
Mech.	7.14	10.66	0.50	5.30	15 268	8482
MPS	7.46	10.71	0.49	5.33	15 311	8506
Method	Moisture	Volatile	Ash	Sulfur	BTU	Calories
Mech.	7.97	10.75	0.54	5.66	15 189	8438
MPS	8.01	10.74	0.54	5.63	15 229	8461

Theory versus reality

The discussion above lays out the reason why most of the modern coal trade is governed by samples collected by full-stream mechanical sampling systems. Even though condition A (stopped-belt sampling) is the theoretically most desirable method, it is not practical in large-scale coal commerce since the conveying equipment simply cannot be stopped and started, under load, multiple times an hour. As such, stopped-belt sampling is only implemented as a reference sample during certification tests (bias tests) or in special circumstances. As such condition B (full-stream sampling) is the better and most practical way to ensure the capturing of the size and moisture distribution of the cargo into the laboratory samples.

The probability samples of condition C and D have their place in the commercial world because full-stream mechanical sampling is not always available – or financially justifiable. But it is important for counterparties in a transaction to understand the limitations and risks of probability sampling and understand how to reflect that in their commercial agreements.

Mechanical part-stream sampling

One example of the need for condition C (part-stream sampling) occurs when the mechanical sampling system in a terminal breaks down or is damaged by debris entering the system. In these cases, it is necessary to balance the time it would take to make the repair versus the cost of stopping the loading.

At most export terminals, a limited amount of time is allowed to make repairs, but there is a manual sampling protocol in place so that loading the ship or barge can continue. This is usually a part-stream sample collected manually with a shovel from a moving conveyor belt. In almost all cases, it is temporary and only small portions of the overall cargo is collected this way.

The ASTM Standard for this type of sampling is D 6609. Even though it is a judgment sample, it is still important to have rules and use common sense to overcome, as much as possible, the inherent challenges in this type of sampling. For example, it is good practice, especially on larger conveyors, to use two personnel so that both sides of the conveyor can be reached by the sampling instruments in order to account for the segregation of material – especially in blends – on either side of the conveyor.

One issue that has emerged in the mechanical sampling world is that many terminals, in their pursuit of economies of scale, are operating at higher and higher flow rates. To accomplish this, the conveyor belts are larger and operate at much higher speeds. In some cases, it is simply no longer safe for the back-up part-stream sampling from the conveyor to be performed manually. In these ports, there is no back-up method other than stopping the loading or sampling at the stockpile – which reverts to using the lowest ranked sampling method and which places a sample technician in a position of danger.

To provide an alternative, Sampling Associates, in cooperation with a mechanical sampling system manufacturer, has developed a sampling device: a Mechanical Part-stream Sampler (MPS: see Figure 2; p. 32). The MPS, which has a patent pending, is still a condition C method; it does not replace condition B sampling. However, because it is fully mechanised and removes the human element, it is a significant improvement on manual part-stream sampling in two important ways.

The first way is that it is much safer. No person is exposed to the moving conveyor parts or harsh weather. Secondly, it removes the human element in the timing of the sample increments and the selection of material into the sample. An additional benefit of using the MPS is that it frees the technician to concentrate on getting the mechanical sampler back online, instead of manually sampling and calling in other personnel. Its main features include:

- All stainless steel construction for long-term prevention of corrosion.
- Two alternating sample scoops to reach both sides of the conveyor (Figure 3).
- The scoops are designed to reach deeper than a person with a shovel can.
- The scoops operate in the same direction of the material flow.
- The frequency of sampling is programmable, based on the lot size and flow rate calculations.
- A small footprint on the conveyor belts.

A number of North American coal export terminals have already installed an MPS or have orders in the pipeline. Table 1 and 2 show data collected at two different terminals (one for coal: Table 1; and one for petcoke: Table 2) comparing the MPS to a sample collected by a mechanical sampling system.

The data is encouraging, indicating that this device is a safe alternative to full-stream mechanical sampling. Even though this device was developed solely as a backup to mechanical sampling at high-volume high-capacity export terminals, its performance has attracted the attention of smaller terminals and petcoke refineries where either cost constraints, or the consistency of the material, allow for the MPS to become a primary sampling option.

Conclusion

In summary, knowing about sampling methods and their limitations is important to both sides in any commercial coal transaction. The probability samples collected by full-stream mechanical sampling will always be paramount. But it is also important to know the judgment sampling alternatives. The development of the MPS introduces an important new alternative method available to the coal industry. WC

Best Practice in Mechanical Sampling

Paul Reagan, of Sampling Associates International, US, reviews the best practice for the organisation and planning of sampling operations.

As ships are loaded at coal terminals around the world, the vast majority of cargoes are mechanically sampled. An improperly operated or poorly maintained machine will produce samples that do not truly represent the cargo and will result in improper assessments of penalties or premiums. This article will survey best practice for system operation and maintenance and highlight an important tool for sampling system operators – the calculation and charting of the sampling ratio.

The sampling system also prepares the sample

A mechanical sampling system does not just sample the coal but it also processes it. Each system consists of stages, each of which has a specific function. The first stage is the primary sampler. This is where the machine first touches coal. The primary sample is usually collected at a transfer point between two conveyors (where a falling stream sampler operates) or directly from the conveyor belt (where a cross belt sampler operates).

The material collected in each operation of the primary sampler is called an increment. Each increment, depending on the system design and the loading rate, can have a mass that ranges from 20kg to as much as 800kg. Many separate increments are collected for each sample (over 100 increments for a 10,000t lot of raw coal). Even the systems that produce the smallest mass increments quickly obtain more coal than can reasonably be transported to the laboratory. As a result, sampling systems are designed to process the coal so only a small, but unbiased, portion is retained and sent to the laboratory for analysis.

The processing includes both crushing (reduction in particle size) and dividing (reduction in mass). It is not uncommon for less than 1 per cent of each primary increment to be retained for analysis in the laboratory.

There are four essential elements of a 'best practice' sampling programme.

- Good organisation and planning of sampling operations.
- Measurements of operational performance.
- Consistent maintenance.
- An effective quality system.

Organisation and planning of sampling operations

The industry standards (ISO, ASTM, BSI, DIN, etc) that govern the practice of collecting samples contain the different specifications and rules to which mechanical sampling systems must comply. These rules determine such things as the minimum size of the apertures in the various sampling devices, the speed at which they should operate, the minimum mass of each increment and the size to which the sample is crushed.

With the design of the sampling system in mind, a sampling plan that adheres to the standards should be developed. These rules must be adhered to in both the collection of the primary increment and the subsequent processing. Because of these strict standards, an important first step in a successful operations programme is having good inspection practices.

Inspections

Inspections can be divided into two groups: those that take place while the sampling system is idle, known as static inspections, and those that take place while the sampling system is operating, known as dynamic inspections. It is good practice to have documented checklists that accom-

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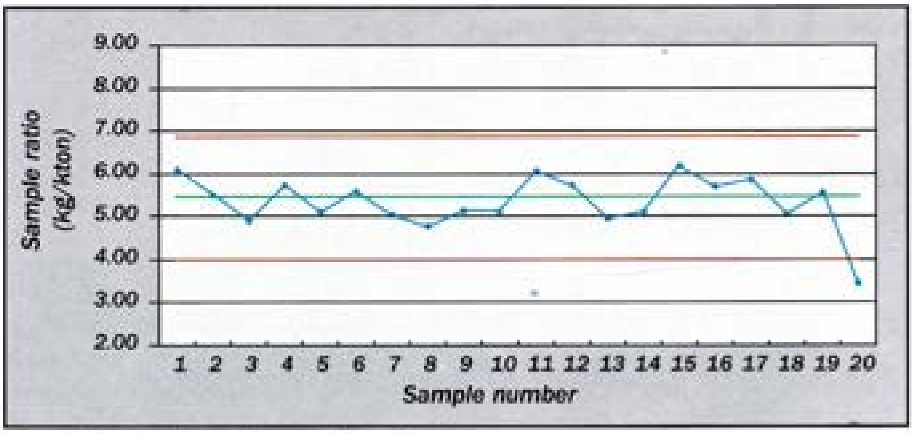


Figure 1. Control chart of sampling ratios.

pany both types of inspections. A standardised written checklist not only reminds the operator of all items that must be inspected but also serves as an historical record.

Static checklists

Static checklists usually involve those items that must be verified prior to the start of sampling as well as items that are impossible or dangerous to check while the machine is operating. Examples of items that would be found on a static (non operating) check list would be cutter openings, the condition of the crusher interior and the belt wiping mechanism on the end of a cross belt sampler. One critical inspection item is how thoroughly the sampling system has been cleaned since the sampling of the previous consignment. Cleaning will be explained in further detail later.

Dynamic checklists

Some items on a system can only be checked while it is operating. These items would be found on a dynamic checklist. Examples would be the speed of cutters, the consistency of coal flow through the system, the proper timing of the frequency of cutters and the speed of feeder conveyors.

Some checklists are hybrids of both static and dynamic items. ASTM D-4702 and AS4264.5 are good places to start when looking for examples of checklists that can be useful to an operation.

Measurements of operating performance

In addition to the inspection of mechanical sampling systems, there are also some very important measurements of operating performance that need to be carried out. These measurements can be divided into two general categories – ongoing and periodic.

Ongoing measurement

All sampling systems are designed to operate according to certain design parameters. They are designed to collect a certain mass of primary increment (relative to flow rate), their internal belts transport the coal sample at certain rates, the crusher reduces the top size to a certain size, and the dividing stages reduce the sample by a chosen ratio. The result of the sampling system operating according to design is that for each set of parameters (lot size, size of cutter, speed of cutter, etc) the system is expected to produce a certain amount of sample mass per 1000t sampled.

The sampling ratio

The ratio of the mass of sample produced by the sampling system per 1000t sampled is called the sampling ratio. This is the most important indicator of sampling system performance. Its measurement, performed on a routine basis during operations, is an essential element of any successful mechanical sampling programme and the cornerstone of best practice.

As each sample is collected, sample weight and lot size data are recorded and observed sampling ratios calculated using the formula – sampling ratio = (sample weight x 1000) divided by the size of the lot (see examples in Table 1). Each of the sampling ratio values, the average sampling ratio value (CL- the central line) and the lower and upper control limits (LCL and UCL) are then plotted on a control chart (Figure 1). The lower (LCL) and upper (UCL) control limits are calculated using average moving range which is the absolute difference between the current sampling ration and the previous sampling ratio (see right hand column in Table 1). The LCL is equal to the CL minus 2.66 times the average moving range. The UCL is equal to the CL plus 2.66 times the average moving range.

Any sampling ratio falling below the lower control limit or above the upper control limit is an 'out-of-control' point, and must be investigated. By investigation and resolution of the causes of out-of-control sampling ratios, one eventually achieves a sampling system that is operating in a stable condition.

Statistically, unless some special cause occurs, there is only a 1 in 100 chance of a ratio falling outside the control limits. As such, any samples with ratios outside the control limits are suspect and an inspection of the sampling system for special causes must take place immediately. Even if a special cause is not determined, vigilance is still necessary. If the operator makes the assumption that any ratio outside the control limits is a normal occurrence (and not due to a special cause), then he would be wrong in 99 out of 100 occurrences. If any special cause is found it needs to be corrected as soon as possible and the laboratory should be notified of a compromised sample.

In the control chart in Figure 1, the last sample is below the LCL. Some reasons for a low ratio are a coal blockage somewhere in the system, some debris in a cutter restricting its aperture, or the operator turning the sampling system off during extremely wet coal to prevent the crusher from plugging. Examples of causes of high ratios exceeding the UCL are a hydraulic leak that would cause a cutter to move through the stream slower than designed, a cutter that is not parked completely out of the coal stream, or an adjustable cutter opening that has loosened and opened up wider than designed.

Once the system reaches a stable condition, and after twenty or more sampling ratio values have been obtained, the average observed ratio is compared to the design sampling ratio (the ratio predicted by the design of the system). If the average observed ratio is not within 10 per cent of the design ratio, the difference between the two must be resolved.

Also, after the condition of a stable system has been reached, one calculates a measure of the variability of the sampling ratio, which is known as the CV or Coefficient of Variation. The CV is obtained by dividing one standard deviation by the average observed sampling ratio to obtain a number expressed in a percentage. CVs of less than 15 per cent indicate good sampling system performance. CVs of over 15 per cent demonstrate too much variation and action needs to be taken to correct some aspect of system performance. There will always be some variability in the sampling ratio and an outstanding CV would still be in the 5 per cent to 6 per cent range.

Periodic measurement

There are several important periodic measurements. Bias testing and measurement of the size consist of the crusher output are the most important.

The bias test is essentially a performance test of the sampling system to determine if there is evidence of system bias. The test entails a comparison of the samples collected by the sampling system to a series of manually collected reference samples to see if there are any biases introduced into the sample by the sampling system itself.

The agreed upon reference sample is almost exclusively a stopped belt sample where the main loading conveyor is stopped under full load and a complete cross section is manually collected (including sweeping all the fines off the belt with a small brush). A series of system samples and corresponding stopped belt samples are collected and analysed to measure overall system performance.

This test is always performed upon the commissioning of a new sampling system and then periodically throughout the life of the system. Before beginning the bias test for a new system, it is preferable to operate the sampling system, collect sampling ratio data, verify that the system is operating in a stable condition, confirm that the Coefficient of Variation is less than 15 per cent, and check that the average sample ratio is within 10 per cent of the design sampling ratio.

The question as to how often a sampling system should be bias tested is often argued. No one would dispute the importance of the test, but it is usually very costly and always disruptive to normal operations due to the many stopped belt samples that need to be collected (in some cases as many as 90 overall). As such, operations personnel would prefer it to be as infrequently as possible but quality control personnel want it as often as possible.

Adding to these considerations is the fact that some systems sample one million tpa while other systems sample 10 million tpa. Can one properly designate a time period for bias testing given such a disparity in volume?

As a general rule, well-maintained sampling systems, operating in accordance with design and in a stable manner, do not need to be bias tested any more than once every 3 to 5 years depending upon their volume. Systems should also be re-tested whenever there is a major component change. At terminals that load a wide variety of coals, selection of the coal to use for conducting the test is an important decision. It is prudent to select coal that is not so homogeneous as it might lead to a conclusion of no bias when there could be a bias when sampling coal with more variability, or blends of more than one coal.

One other useful periodic measurement is to check on the size consist of the material produced by the sampling system after any crushing stage. Sampling system crushers are designed to produce a certain top size (4 mesh, 8 mesh, 10mm, etc.) for the final sample. However, crushers are usually high wear items and their ability to operate according to design can quickly degrade. This can impact the sample in the ability of dividers 'downstream' being able to operate properly (because they are also designed to work only on a certain top size coal).

Checking and tracking the performance of the crushers periodically, and at least monthly, will provide early warning of when the crusher components need to be replaced. Such checks are both a quality control measurement and a part of the maintenance programme.

Table 1. Example of observed sample ratio calculations.

Sample no.	Sample mass in kg	Tonnes in lot	Sampling ratio	Moving range
1	19.8	3250	6.09	
2	27.5	5000	5.50	0.59
3	23.4	4789	4.89	0.61
4	12.3	2145	5.73	0.84
5	12.0	2350	5.09	0.64

Maintenance is essential

A good preventive maintenance (PM) programme is an integral part of proper mechanical sampling. In simple terms, a mechanical sampling system, even the most automated one, is a machine. As a machine, its components are subject to wear, breakdown, corrosion and malfunction. The result of such forces will be poor samples. Good maintenance of equipment is essential and it is necessary to ensure it is consistently performed.

In many cases the terminal or plant personnel perform the maintenance of the sampling equipment. While they are skilled and certainly have the ability to perform the maintenance, each day they are forced to select from their numerous maintenance priorities. When faced with a conveyor belt or a shiploader problem, the sampling systems slip to the bottom of the list. The condition of many sampling systems reflects the long-term effects of this daily slipping down the priority list. In many cases, unless it has completely stopped running, the sampling system does not get the attention it needs.

There are certain malfunctions that disrupt the system so much that the machine simply stops running and no sample can be collected for the laboratory. Such occurrences will always receive a response. However, there are problems that occur that can affect the sample but do not stop sample collection. In other words, coal sample continues to appear in the sample container but that sample is compromised. These latter cases must be detected and corrected.

Common problems

While there are too many examples of how poor maintenance can affect the quality of the samples to mention them all in this article, there are a few very common occurrences that illustrate the problem. In Figure 2, there is a diagram of a very simple piece of equipment, a conveyor belt scraper. The purpose of this scraper is to prevent coal fines from being carried back on the underside of the belt and to ensure that they remain in the processed sample.

In Figure 2 the scraper is worn and not doing its job. In the case of a typical steam coal, the fines contain higher ash and lower heat content. Instead of being scraped off the belt and remaining in the processed sample, with a chance to be included in the sample sent to the laboratory, these fines are lost. In this case, the sample sent to the lab will have a lower ash and higher Kcal than are really in the consignment.

Another common maintenance problem is on the sweep arm (cross belt) samplers. The primary samplers on this type of system are equipped with a hard rubber or plastic wiper, which actually makes contact with the conveyor belt to ensure collection of all the coal in the cross section selected. This is a high wear item. Access is often difficult and usually involves locking out both the sampling system and the conveyor belt to adjust it safely. Failure to frequently adjust and replace this wiper will cause the primary sampler to fail to obtain the coal (frequently the fines) closest to the conveyor belt.

A third and final example is poor maintenance of the parts of the sampling system that make it airtight – belt skirting, door seals and baffle curtains. One of the main sources of bias in a sampling system is change in the moisture content of the sample – introduced during sample collection and processing. Air will flow through many systems, particularly those with hammermill crushers, and care needs to be taken to prevent this tendency from drying out the samples. Failure to do so will allow a moisture bias to be introduced to the sample.

There are a number of main objectives of a PM programme.

- To maintain the airtight integrity within the sampling system.
- To ensure the sampling system does not introduce bias into the sample.
- To be sure the system continues to operate as designed.
- To prevent corrosion and to extend the useful life of the equipment.
- To prevent rather than just react to problems.

This latter point is important. The sampling ratio described earlier is an invaluable tool in detecting problems. A well-planned and implemented maintenance programme, however, prevents many problems from ever occurring.

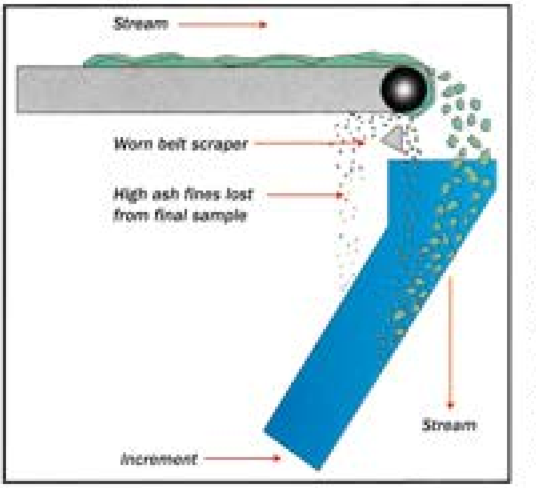


Figure 2. Belt scraper.

Records

A thorough PM programme requires a lot of documentation. Such documentation would include:

- A log of all required PM checks and inspections which serves both as a reminder of the frequency of tasks and a record of when they are actually performed.
- A written procedure for each PM task.
- A written record of any failure during operations and the measures taken to correct it.

In a PM log, it is a good idea for sampling system PM to be scheduled based on the hours of operation rather than calendar time. An hour meter is simple to install for this purpose. That way, maintenance is performed according to the amount of use the system is receiving and the system gets checked more frequently during periods of high use.

Cleaning

It can be argued that cleaning is not part of maintenance and is more operations, but the fact remains that cleaning is important. Frequent cleaning of the sampling system prevents contamination between different coal consignments, prevents coal from drying out (or freezing) and being mixed with the next sample (even if it is the 'same' coal) and also is very important in preventing corrosion. Because coal can be wet, leaving coal in a sampling system encourages corrosion of components and housing steel. Good sampling practice necessitates frequent cleaning. Installation of compressed air stations at strategic locations around a sampling system is highly recommended to aid the cleaning process.

Quality system

A good quality system such as ISO 9002 is indispensable. While a full discourse on quality system requirements will not be offered here, it is important to cover one critical element: problem resolution. Great emphasis needs to be placed on problem resolution and correction. A sampling programme involves much more than the operation of a clean, well-maintained system. It also needs to deal with many variables such as the different sampling requirements of different consignments or clients, the ever-changing operational plans of the terminal or even such mundane things as a change in the load plan by the ship's master.

Problems will arise. Mistakes will be made. The critical element of any quality system is what is done about them. The first step is always to take the immediate action necessary for resumption of coal loading and sampling, and to determine the disposition of any suspect sample. Next, one must carefully examine the causes of the problem and determine the changes (in operating procedures, equipment, etc.) that are appropriate to prevent recurrence. It is this second, most important, step that is often neglected.

The ultimate resolution of any problem is preventing its recurrence. The goal of a quality system is continuous improvement. Continuous improvement requires that problems be documented, discussed, and examined (at all levels of the company) and that measures be implemented to keep it from happening again. Solutions to various problems range from changing an operational procedure to changing the type of equipment used at a certain stage of the sampling system. Whatever the resolution, continuous improvement requires commitment.

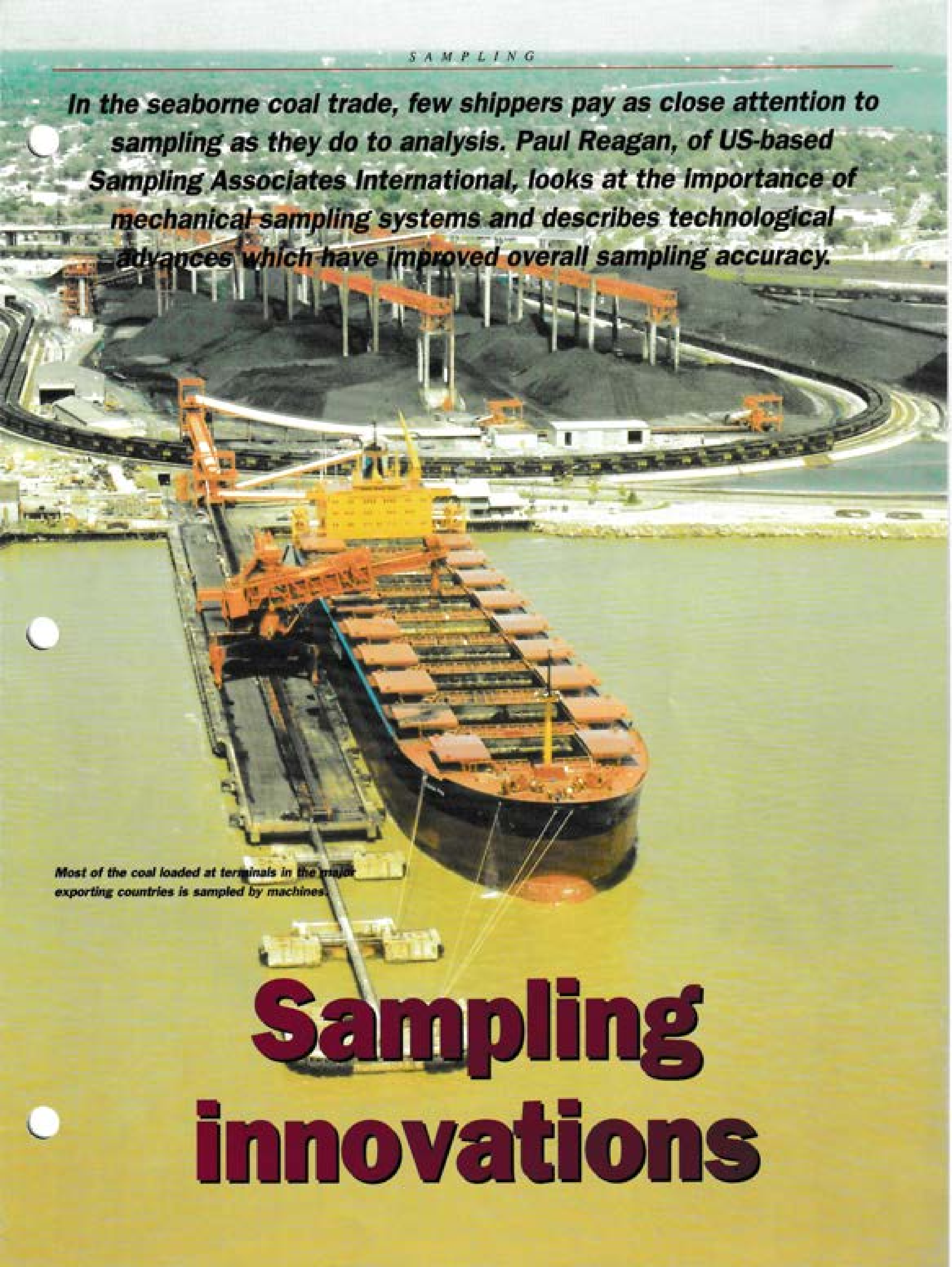
Conclusion

The four essential elements of the best practice in mechanical sampling have been identified. Of course, the proper implementation of these elements comes down to the people responsible for execution. Many well-designed programmes fail to achieve the intended results because the people responsible do not perform.

As such, responsible personnel need to be well trained. They need to understand what the machine is doing and, more importantly, how to identify when it is not working properly. If possible, it is good practice that the people that operate the machine also participate in the execution of the PM programme. This provides the double benefit of solving the low priority that traditional maintenance personnel give to sampling system maintenance, and it provides the operating personnel with valuable information on the inner workings of the components of the sampling system. Involvement in the execution of the PM programme will provide them with enhanced abilities to detect and prevent potential failures.

However, good training requires resources. The bottom line on a truly good sampling programme is that the people that write the cheques ensure that sampling is given the necessary emphasis. Since sampling is so important, its status needs to be made clear by senior management.

In the international coal trade, proper sampling is taken for granted. Ultimately it should be because good sampling means trade takes place without incident. As such, a good sampling programme which runs without incident, becomes 'out of sight, out of mind'. But there is a difference between being taken for granted and being neglected. It can only be taken for granted when the proper care and attention are provided. ■



In the seaborne coal trade, few shippers pay as close attention to sampling as they do to analysis. Paul Reagan, of US-based Sampling Associates International, looks at the importance of mechanical sampling systems and describes technological advances which have improved overall sampling accuracy.

Most of the coal loaded at terminals in the major exporting countries is sampled by machines.

Sampling innovations

When money changes hands in the sea borne coal trade, the amount is determined by the sampling and analysis of the cargo – most frequently as the coal is being loaded. While the analytical results are used to determine the amount of money that changes hands, most technical experts agree that sampling is the most critical part of the process. Few coal shippers pay as close attention to the sampling as they do to the analysis.

It is an accepted norm among most sampling industry experts that 80 per cent of the errors in test results are attributable to the sampling (with 20 per cent to the analysis and preparation – figure 1). The best laboratory in the world is of little use if the sample was collected improperly. As a result, good sampling practice is essential.

Most of the coal loaded at terminals in the major exporting countries is sampled by machines. While manual sampling is still performed in many places, at the large exporting terminals it is rare. The preferred method for collecting samples is through the use of mechanical sampling systems.

Table 1. Capturing the correct particle size distribution in the sample

The important chemical properties of coal (moisture, ash, sulfur, BTU) are not distributed equally in the particles of different sizes.

Example

1. A consignment of steam coal is analysed (14.3% ash, 12,857 BTU)
2. Separate analyses of the different sized particles show:

Size (mm)	% In consignment	Dry ash	Dry BTU
+50	6%	12.1%	13,185
50x25	24%	12.6%	13,110
25x12.5	20%	13.3%	13,005
12.5x6.3	22%	14.8%	12,780
6.3x0	28%	16.5%	12,585
	100%	14.3%	12,857

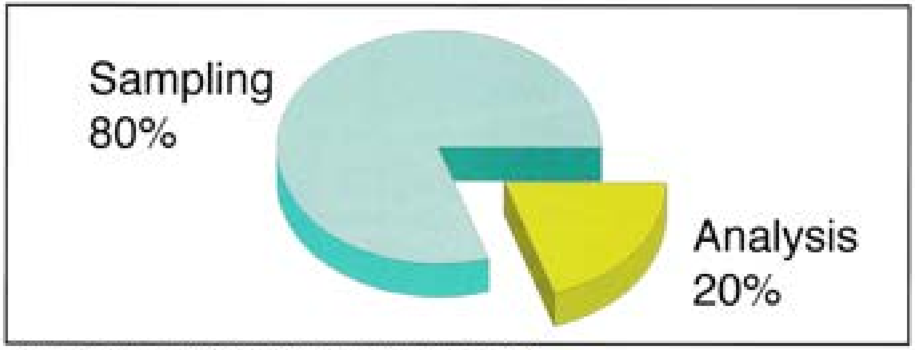


Figure 1. Errors attributable to sampling and analysis.

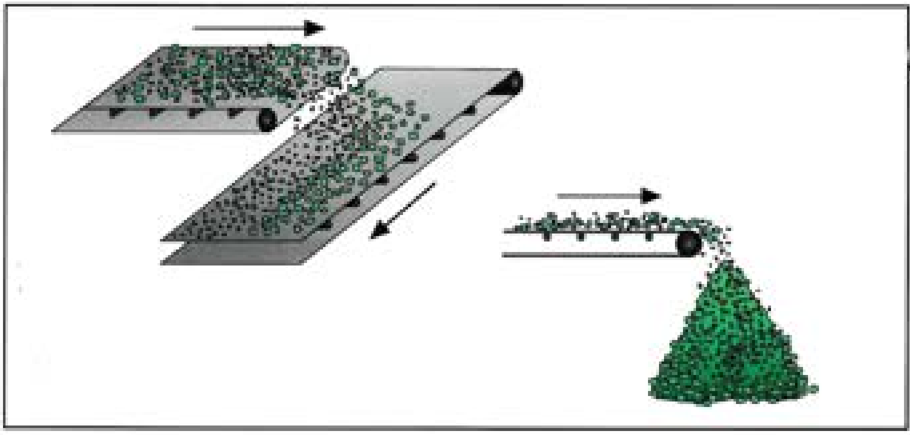


Figure 2. Segregation of coal pieces by size during transportation.

Mechanical sampling

To achieve sampling accuracy, it is important to have the ability to obtain and process individual sample increments that correctly represent the true characteristics of the material being sampled. A sample increment is the amount of coal that is collected by one action of the sampling device. For each sample analysed, many increments need to be collected and processed together. The number and mass of increments are spelled out in the sampling standards. Both ISO and ASTM sampling standards recognise that the most accurate way to sample coal is by obtaining increments that consist of full cross sections of the coal while it is being moved by conveyor.

A full cross section in each increment is required because the important chemical properties of coal (such as ash and Btu) are not homogeneously distributed in the particles of different sizes. In other words, the smaller particles in a coal consignment (0mm x 6.3mm) often contain different ash and Btu than the larger particles in the same consignment. A typical example can be found in table 1 which shows the analysis results of a steam coal cargo from a single source mine.

The ash is much higher and, consequently, the Btu lower in the smaller particles in this particular coal. This variance in the distribution of chemical properties between different size fragments means that the essential challenge of sampling is to duplicate in the collected sample the size distribution that exists in the consignment. This is not so easy to do. Coal is notorious for segregating by size particles when handled: fines will segregate from the larger pieces when the coal is moving on a conveyor, when transferred from one conveyor to another, when stacked in a stockpile and when transported in rail wagons (figure 2).

If the size distribution in a collected sample does not match the distribution in the consignment, then the sample will produce an erroneous test result. In the example in table 1, too many fines in the sample leads to incorrectly higher ash and lower Btu, while too few fines leads to the opposite. In either case, the sample will be inaccurate if the size distribution in a collected sample does not match the distribution in the consignment. Sampling must therefore overcome the tendency of coal to segregate by particle size. The best way to be sure of this is to stop the conveyor belt at regular intervals and take a sample consisting of a complete cross section of the coal. The cross section removes the proper proportion of sized coal and fines regardless of any segregation.

Since repeatedly stopping large conveyor belts loaded with coal is not practical, then cross section sample increments must be taken while the conveyor belt is moving. The only way to do this is to use a machine – a mechanical sampling system.

Two types of sampling systems

There are two basic types of mechanical sampling systems. The main difference between the two systems is the location where the primary increment is collected. The first type collects the primary increment by passing its collection device (primary cutter) from a falling stream of coal at a transfer point between two conveyor belts. This type is called a cross stream cutter (figure 3). The second type collects the primary increment from the coal as it lies on a moving conveyor belt. Essentially, the primary cutter rotates through the coal and sweeps the cross section off. This type of sampler is called a cross belt (or a sweep arm) sampler (figure 4).

Both types of system include sub-systems of other components that process the coal, essentially duplicating the reduction (crushing) and division (riffling) of bulk samples that would take place at the laboratory. Both systems produce a sample that represents the consignment but is small enough that the subsequent laboratory preparation prior to analysis is kept to a minimum. All coal from the primary increments that is not sent to the laboratory (called the reject) is mechanically placed back onto the moving conveyor belt and, in this way, an enormous amount of physical handling of the samples is eliminated.

There is, however, a significant difference between the number and size of the components on cross stream cutters and cross belt cutter systems required to perform the processing. While the size of primary increment is always a function of the tonnes per hour rate of the loading system, cross stream cutters usually take much larger primary increments than cross belt systems.

The cross stream cutter collects its sample increments in a plane parallel to material flow. This orientation adds a factor of 'time in flow' to the cross stream increment mass. When combined with cutter speed limitations recommended by ASTM & ISO for the cross stream cutter, the result is a primary increment mass of four to six times that of a comparable cross belt systems on the same conveyor. On high capacity conveyors, cross stream primary increments of between 300kg and 1000kg are commonplace. Alternatively, the cross belt cutter's orientation is perpendicular to the material flow and it faces no restrictions on cutter speed. On the same high capacity conveyors, cross belt primary increment would be between 50kg and 200kg.

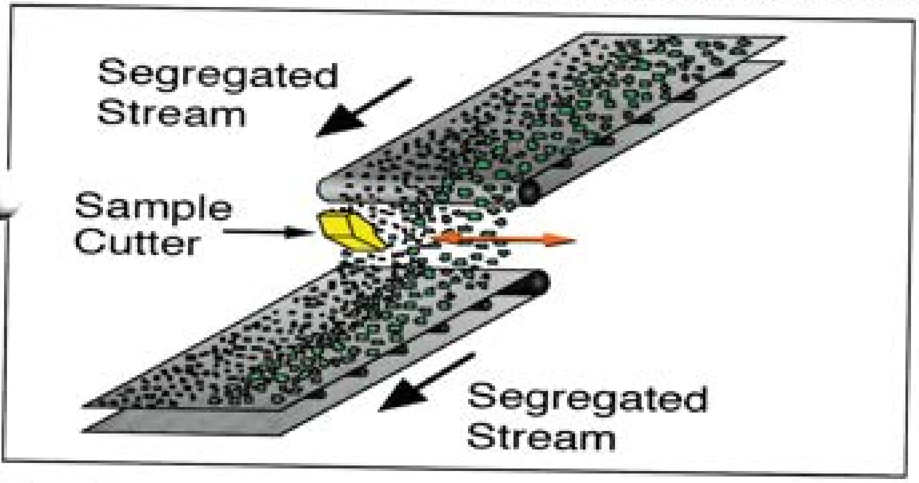


Figure 3. Sample collection at a transfer point between two conveyor belts.

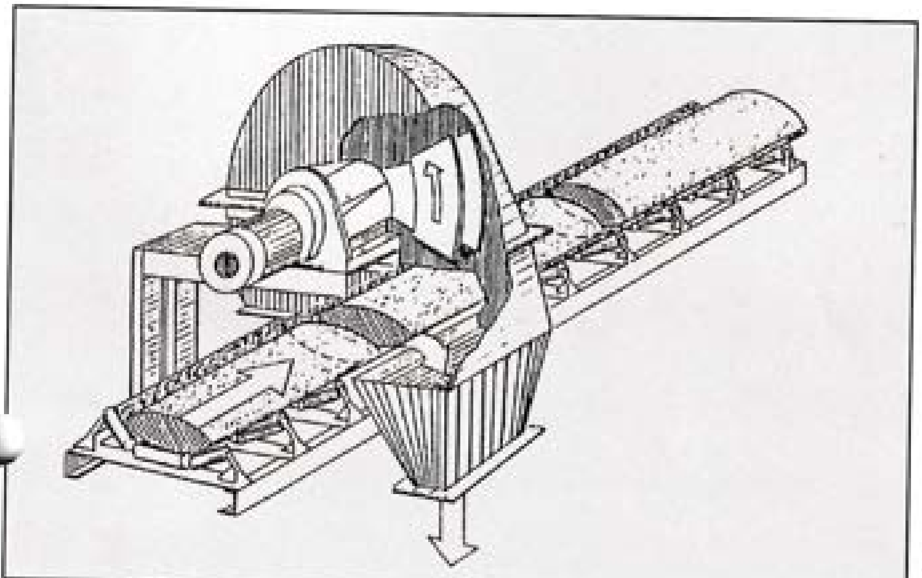


Figure 4. Cross belt or sweep arm sampler.

With substantially more primary increment material to process, the 'downstream' or sub-system components of cross stream systems are usually much larger in size, complexity and number, with three to four stages of sample division typically required to achieve a final sample. Cross belt systems typically accomplish the same task in two stages. The resulting difference in system size is dramatic and understandably influences their comparable costs.

Cross belt samplers also enjoy a logistical advantage in location and accessibility. All they need for installation is sufficient room for the primary sampler at a point along the length of a conveyor belt and the downstream processing components can be located for easy access at grade level. Retrofit installation on existing conveyors is easy, economical and commonplace. Cross stream samplers must always be located at the end of the conveyor belt and they additionally require sufficient height to accommodate the larger number of downstream processing components. As such, the cross stream system is typically engineered at the same time that the conveyor belt system (with the needed transfer point) is designed and retrofit installations are rare.

Despite these advantages, cross belt samplers were slow to gain widespread acceptance for years after their introduction. However, technological advances have now overcome this resistance and cross belt samplers have become so popular in the US that the installation of cross stream cutter sampling systems is becoming extremely rare – even at new terminals with the opportunity to design the needed transfer point.

Innovation in mechanical sampling systems

Sampling systems in the latter part of the 1990s are very different from the sampling systems of the early 1980s – the time when the widespread use of mechanical sampling started. Many of the sampling systems in use today were installed many years ago and although the challenges of sampling and processing coal samples have not changed, the engineering and technology has certainly advanced. Many of these advances can be retrofitted into older sampling systems.

Areas of innovation

The full cross section

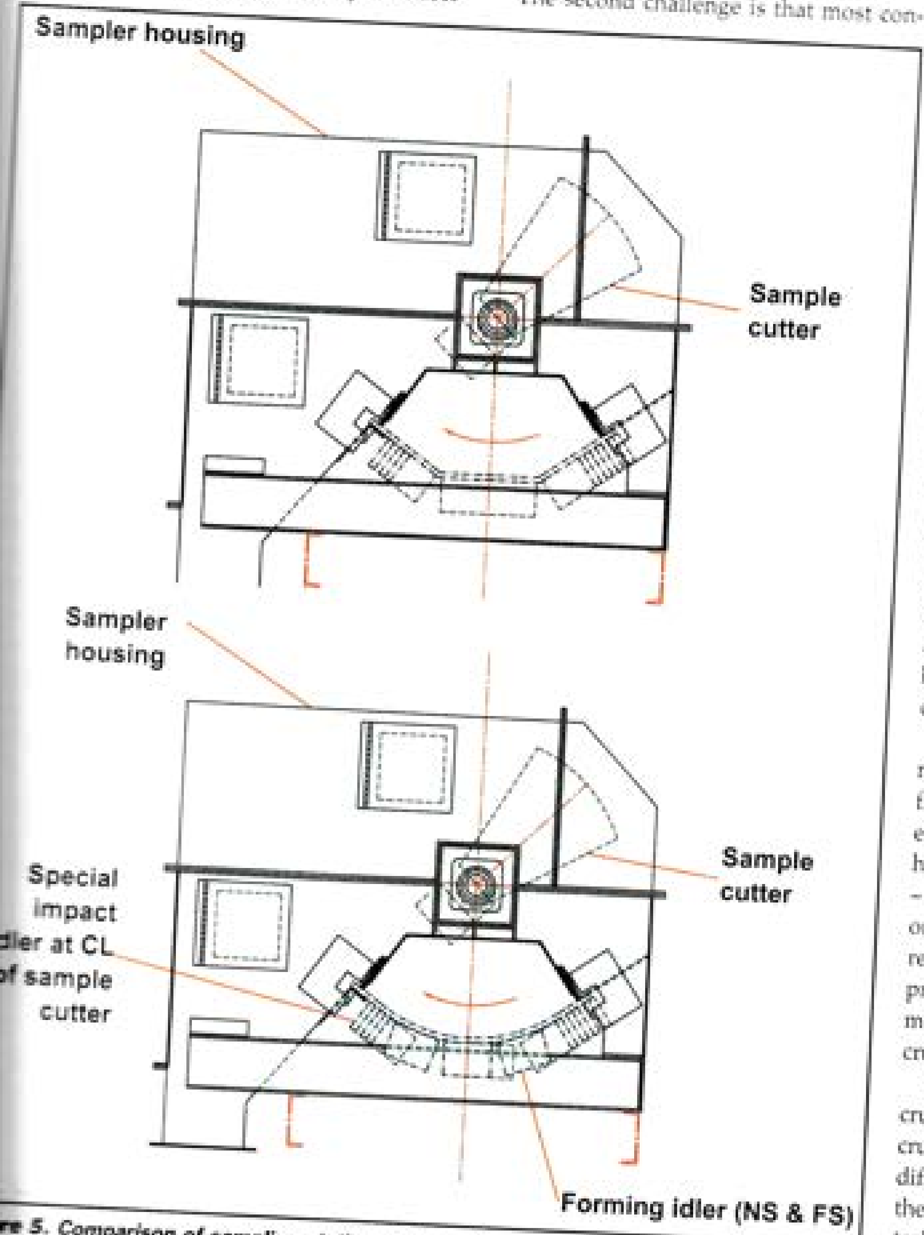
The necessity to obtain a full cross section of the coal in each increment collected is well satisfied by a cross stream cutter but at the cost of a very large primary increment and more robust processing equipment. The cross belt samplers reduce the mass of the sample increment but their ability to collect a full cross section was slow to be accepted. The initial resistance to cross belt samplers was fuelled by doubt regarding their ability to collect a representative primary increment. One of the most important advances in mechanical sampling overall has been the proven ability of cross belt samplers to collect representative primary increments.

There are two special challenges for a cross belt primary sampler to extract a full cross section. Firstly, in order to collect the fines that tend to move closest to the conveyor belt, the primary sampler needs to touch the belt. Understandably, this point of impact is an area of high wear and needs to be constantly adjusted to prevent a gap developing between the edge of the sampling mechanism and the conveyor belt.

The second challenge is that most conveyor belts are not configured in a perfect arc. The support idlers usually cause the belt to take on the shape of the idler racks (figure 5) and without some modifications, the coal in the junction areas between the corners of the belt cannot be collected.

This problem is exacerbated if the location of the conveyor idlers is far apart at the location of the primary sampler. If the idlers are far apart, the belt can sag between them, moving the belt away from the primary sampler and potentially allowing part of the increment to escape under the sampling device.

In the newest sampling systems, the full cross section problem has been virtually eliminated. Most new systems have a set of special impact idlers, or even a full impact 'saddle' placed under the conveyor belt at the point of impact. This eliminates any effects of conveyor belt sag. In addition, special idlers of a declining degree of angle are often added before and after the point of impact to gradually reshape the contour of the belt to eliminate the 'corners'. In an innovative approach, one manufacturer has developed a patented support mechanism that pneumatically lifts the belt into a perfect contour shape for the brief time the primary increment is collected (figure 6)



...re 5. Comparison of sampling stations; above, the unmodified station and below a ...ling station fitted with special impact idlers to generate a perfect belt contour.

Crushing the coal

After collecting a full cross section primary increment, the next major challenge of mechanical sampling systems is to crush those increments to a topsize suitable for the laboratory (so that further crushing in the laboratory can be minimised) without influencing their moisture content. To accomplish this goal, the crusher needs to be free of plugging and easy to inspect, clean and repair.

There are two types of crushers in mechanical sampling systems for coal. The first is a hammer mill crusher which employs high rpm internal rotors that rotate hammers and crush the coal by impact – driving it through a barrier (either a screen or a series of closely spaced bars). As a result, these crushers are very effective at producing coal of a low enough topsize (4 mesh or lower) that eliminates further crushing at the laboratory.

The downside of some hammer mill crusher designs is that the high rpm of the crushing hammers can create an air pressure differential in the upper and lower parts of the crusher and cause airflow. When uncontrolled, this airflow can lead to moisture loss in the sample. Another problem with hammer mill crushers...

alloys in their internal parts, they can wear quickly. The most important variable affecting the crusher performance is the size of the gap between the tip of the crushing hammer and the screen (or bars) against which the coal is crushed. As the hammers and screen wear, the gap grows, crusher efficiency declines and can lead to increased plugging.

The second type of crusher is a roll crusher. These crushers utilise a very slow rpm cylinder (or 'roll') which crushes the coal against a fixed plate or another roller that is also rotating slowly. Roll crushers have some advantages. The first is the slow rotation of the rolls which produces lower airflow and lessens the potential moisture loss. Secondly, they tend to wear more slowly and, most importantly, as wear does occur, they can be adjusted to keep the crushing gap consistent. Finally, they can be less prone to plugging with fine and sticky coals.

One downside of the roll crusher is that, for a given size, they have less crushing capacity than a hammer mill. Another downside of roll crushers tends to be in efficiency. The coal is not being forced through a barrier like a screen, therefore most roll crushers are unable to produce a product with a topsize much less than 3/8" and an extra off-line crushing stage is required in sample preparation at the laboratory. Not only is this expensive and time consuming, but the extra handling and crushing exposes the sample to moisture loss.

The larger top size of the coal in the sample often requires additional crushing and handling at the laboratory and this extra handling can increase preparation errors and expose the sample to moisture loss. Hammer mill proponents would argue that it is imperative to avoid this extra handling at the laboratory. Roll crusher advocates would counter that it is much more important to avoid the downtime associated with frequent crusher plugging. Weighing the pros and cons of the two different types of crushers often comes down to the topsize and moisture content of the coals that need to be crushed. Wet and fine coals cause problems for any crusher, but roll crushers tend to have a better record with them. However, avoiding the further handling and crushing at the laboratory is important and so a well designed hammer mill crusher has a distinct advantage.

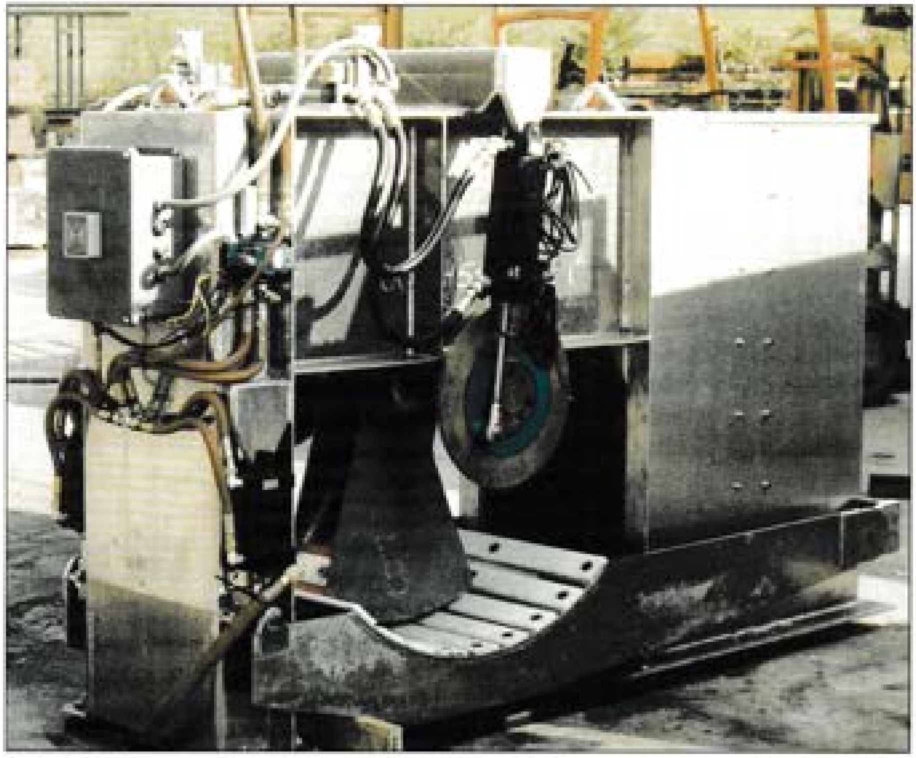


Figure 6. Support mechanism for shaping the conveyor belt to the required contour for precise sampling.

Advances in crusher design

There have been a number of important advances in crusher equipment, particularly hammer mills. The first is reduced wear from hammers made of hardened hybrid alloys and the second is improved access to the crushers for cleaning and replacement of worn parts.

One of the long standing problems with mechanical sampling systems has been the fact that access to the components for cleaning and maintenance has been poor, especially in the crushers. Given the wear and plugging described earlier, this poor access has caused problems for sampling system operators. This key weakness has been addressed in recent crusher designs.

The McLanahan Corporation has recently introduced a crusher that has rapidly gained popularity due to its ease of access (figure 7). One of the most advanced crushers is one produced by JB Long Company of Knoxville, Tennessee, US. It is a hammer mill but it has been engineered with a special housing design and a heavy emphasis on air seals so that it can operate at very high rpm's without moisture loss.

The high rpm's allow it to obtain the same topsize in the coal but with larger openings in the screen plate. These larger openings greatly increase the open area of the screen and dramatically reduce the tendency to plug. In addition, a special mechanical wiping arm has been added to the crusher inlet chute (a notorious location for plugging) to periodically remove any coal buildup in this sensitive location. The addition of an optional hydraulic lifting mechanism to open the crusher easily has increased the popularity and effectiveness of this machine.

Command and control

There is no doubt that the introduction of the programmable logic controller (PLC) into mechanical sampling systems has been a major advance. The PLC is simply a small computer which controls the sampling system components through software programs. Sampling system components need to be integrated to run properly and smoothly. Start up/shut down sequences, fault alarms, and the proper timing and operation of different functions all need to be carefully controlled. In older systems, this would be hard wired utilising a massive array of wires, timers, relays and motor starters. Today, most of this can be replaced by the silicon chip.

In addition to simplifying the electrical portion of a mechanical sampling system, the PLC has provided several important capabilities. The main one is the ability of the PLC to collect and transmit data regarding the sampling operations. Key data that used to be recorded by hand is now stored in the PLC and can be printed out and manipulated to produce sampling reports and quality control data, such as date/time operation data, number of primary cuts and number of secondary cuts. When combined

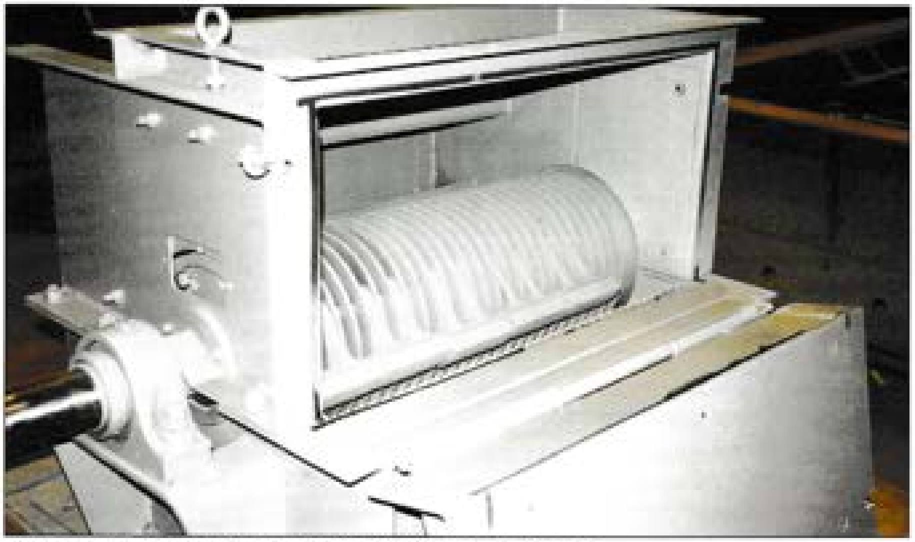


Figure 7. Mclanahan Corp. crusher showing ease of access.

with a scale for determining the sample mass, statistical process control charts can be produced automatically – further enhancing operations.

A second major advantage of PLC controls is the ease of trouble shooting problems and malfunctions. The older (non PLC) systems would often require painstaking searches for the source of a problem with a voltage meter. With the use of the LED lights on the I/O modules, the problem location time on PLC controlled systems is vastly reduced. PLC systems can be programmed to specifically identify the source of failure and send that message to the operator. The inclusion of a modem allows for the diagnosis of problems over telephone lines. One manufacturer includes an option where the PLC automatically places a telephone call to a pager carried by the technician to notify them when system problems occur and their source.

The early sampling systems were not designed with the human operator in min Newer systems have improved conditions for operators.

A final word on maintenance

The sampling of coal with machines is commonly referred to as 'automatic sampling'. While many of the innovations discussed have moved the industry closer to the goal of being fully automatic, these systems are still machines and need proper care. Any purchaser of an 'automatic' system that overlooks routine inspection, cleaning and maintenance will be disappointed.

Sampling systems, like any machine, need good preventive maintenance, especially on the high wear items. When multiple sources of coal are sampled, they need frequent and thorough cleaning and they also need rapid resolution of problems and malfunctions. The result of a sampling system that is poorly cared for is not just reduced output or inefficient operation, but erroneous samples. In such a case, the laboratory can be perfect but they will get th wrong answer.