

RISK MANAGEMENT AND THE DETERMINATION OF THE GROSS CALORIFIC VALUE OF COAL*

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INTRODUCTION

When coal is traded on the open market, the objective is to buy or sell a quantity of coal for its energy content. Coal is normally traded with its energy content, i.e., its Gross Calorific Value (GCV), expressed in terms of one of the following units of measure:

ASTM D 5865-02, Standard Test Method for Gross Calorific Value of Coal and Coke:

X1.4.1 The gross calorific value can be expressed in joules per gram, calories per gram, or British thermal units per pound. The relationships between these units are given in the table below:

$$1 \text{ Btu} = 1,055.06 \text{ J}$$

$$1 \text{ calorie IT} = 4.1868 \text{ J} \quad 1 \text{ J/g} = 0.430$$

$$\text{Btu/lb} \quad 1 \text{ J/g} = 0.239 \text{ cal/g} \quad 1 \text{ cal/g} \\ = 1.8 \text{ Btu/lb}$$

Kilocalories per Kilogram (Kcal / Kg) is numerically equivalent to the calories per gram.

Among the uninformed, confusion can arise between the two terms Gross and Net Calorific Value (GCV and NCV); here are the ASTM definitions:

ASTM D 5865-02, Standard Test Method for Gross Calorific Value of Coal and Coke

3.1.4 gross calorific value (gross heat of combustion at constant volume), Q_v (gross)—the heat produced by complete combustion of a substance at constant volume with all water formed condensed to a liquid.

3.1.7 net calorific value (net heat of combustion at constant pressure), Q_p (net)—the heat produced by combustion of a substance at a constant pressure of 0.1 MPa (1 atm), with any water formed remaining as vapor.

In its simplest form, the GCV is the maximum amount of energy that

could be extracted from the coal under controlled conditions, e.g., as determined in a laboratory bomb calorimeter. Likewise, the NCV is the maximum amount of energy that could be extracted from the coal at the conditions at which the power plant is operated (i.e., with the generated steam being released to the atmosphere, without benefit of recovering the latent heat of condensation). NCV is smaller than GCV.

There is an interest in GCV because this is the most commonly used measure for purchasing energy that is used for producing steam for driving turbines. The value determined for GCV can affect the values calculated for the plant heat rate and for the plant total energy efficiency: (*Babcock & Wilcox, Steam, 40th edition*) $\text{Net Plant Heat Rate (NPHR)} = \text{total fuel heat input (Btu)} / \text{the net busbar power leaving the plant (KWh)} = \text{Btus/kWh per unit time. (The NPHR typically varies with plant load.)}$

$$\text{Plant total energy Efficiency (E)} = (3,412 \text{ Btu/kWh} / \text{NPHR}) * 100\%$$

FAIR TRADE

There needs to be assurance that the energy content of the coal is as warranted in order that there be confidence in the fairness of the trade.

To be fair, both the quality and the quantity of the coal need to be determined accurately and precisely. Both of these characteristics are important; the focus cannot be on one at the neglect of the other. If 10,000 tons of

12,000 Btu/lb coal are to be traded, there must be systems in place to assure the accuracy of the needed measurements and the validity and the traceability of the collected samples.

Determining the quantity of a cargo of coal depends upon agreement among the interested parties of the following elements:

- The method to be used to determine the weight of the cargo
 - Weigh bridge - belt scale, truck scale, railroad scale
 - Displacement method - vessel draft survey, barge draft survey
- The location of and the responsibility for making this measurement
- The desired level of accuracy and precision of the measurement
- The level of certification of the measurement process
- The experience and knowledge level of the persons making the measurements, performing the calibrations, and certifying the processes

Determining the quality of a cargo of coal depends upon agreement among the interested parties of the following elements:

- The method to be used to collect a sample of the cargo
 - Manual collection method (stockpile, off-the-belt, truck top, wagon top, hopper, etc.)
 - Mechanical collection method (auger, cross-belt, cross-stream, etc.)
- The location of and the responsibility for taking this sample
- The method for identifying, securing,

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and delivering the sample to the preparation site

- The method and equipment to be used in reducing and dividing the sample for laboratory analysis
- The method for identifying, securing, and delivering the sample to the laboratory
- The method to be used to determine the chemical and physical characteristics of the cargo
- The desired level of accuracy and precision of the measurement
- The level of certification of the measurement process
- The experience and knowledge level of the persons making the measurements, performing the calibrations, and certifying the processes

Since coal will oxidize once exposed to the atmosphere, the GCV may change all along the supply chain, depending upon techniques used in storage and handling and upon the efficiency of the delivery systems. The methods used in sampling and testing can affect the ability to detect these changes. To understand the GCV content of a coal and the effects of processes and systems upon GCV, appropriate coal sampling, preparation, and testing techniques must be used.

PURCHASE DOCUMENTS

Buyer and Seller usually express their agreed methods for determining quantity and quality in a contract, a purchase order, or some similar document that discusses these specific elements as well as others, e.g., price, delivery guarantees, penalties, premiums, dispute settlement, extension options, cancellation options, force majeure, etc. Therefore, the first essential element for assuring that proper consideration is given to quantity and quality assurance is that **an experienced and knowledgeable technical expert must be involved in the contract development / review process.** The technical expert's knowledge of the pitfalls involved in determining quantity and quality will help resolve potentially contentious issues before they ever come forward.

QUANTITY DETERMINATION / CONTROL

Usually, much more time and effort is expended on quality determination / control than is on quantity determination / control. There may be several reasons (and possible misconceptions) for this:

1. It is possible to ask for a reprep or a recheck of a laboratory analysis; it is not always possible to ask for reweighing / resampling of a lot of coal.
2. It is easier and much less expensive to ask for a reprep or a recheck of a laboratory analysis than it is to reweigh or resample a lot of coal.
3. Laboratory testing lends itself much more easily to monitoring and control than is weighing or sampling.
4. Typically, rail scales or truck scales are certified by some governmental or quasi- governmental agency. And, you can't fight city hall!

Today's electronic weighbridges, scales, etc. lend themselves much more readily to quality control / assurance. Calibration is much easier than in the past and monitoring of some scale performance criteria can be conducted from a remote location.

Buyers or Sellers, to protect their own interest, can have their own representative monitor scale calibrations and verifications and / or to perform their own inspections on a regular basis.

SAMPLING

The process for determining the quality (GCV) of coal begins with sampling, a process that is not as easy as it may appear on the surface; note what ASTM says about the subject:

D 2234 - 00, Standard Practice for, Collection of a Gross Sample of Coal Coal is one of the most difficult of materials to sample, varying in composition from noncombustible particles to those which can be burned completely, with all gradations in between. The task is further complicated by the use of the analytical results, the sampling equipment available, the quantity to be represented by the sample, and the degree of precision required.

The value of a coal cargo is determined from testing a sample collected by a human or by a mechanical coal- sampling system. Should the sampling method be biased or inconsistent, or if the sample preparation method results in a subsample that is biased or inconsistent, the value of the cargo can be inaccurately or imprecisely determined, the cargo can be over- or under-valued, and the buyer or seller can be erroneously compensated for the value of the cargo. Expensive, wrong decisions can be made based upon biased, incorrect, or erratic data.

In sampling a lot of coal, it is important that every particle of coal in the lot has an equal opportunity to be collected in the sample. If this is not the case, the sample is not representative of the lot, but only of that portion from which particles were collected.

A common mistake that is made in preparing sampling requirements in contracts is in not requiring 100% sampling. Sometimes this error is expressed by not requiring all wagons in a rake to be sampled, but, instead, perhaps only 25 or 40%. Likewise, sometimes not all rakes from a particular Supplier may not be sampled; instead, only 50% of all the rakes could be sampled. These practices do not allow for every particle in a lot or in a series of lots to have an equal chance of being sampled. Some particles have 0% chance of being sampled (i.e., those wagons or rakes chosen not to be sampled). Every wagon or rake must be included in the sampling scheme.

MECHANICAL SAMPLING SYSTEMS

Mechanical sampling is preferred over manual sampling because there is no human discretion involved. Human discretion may lead to bias, intentional or accidentally. The mechanical coal-sampling system (MCSS) is costly to purchase, install, and maintain, but its increased accuracy and precision may well be worth it, especially in those operations that buy or sell very large amounts of coal on an annual basis.

A MCSS must be properly designed for

the application in which it is to function. The MCSS should be performance (bias) tested and be subject to ongoing Quality Assurance, including periodic critical inspections (audits) and statistical process control (SPC) monitoring and control.

DESIGN

It is impossible to design an effective MCSS without detailed information about the location of the MCSS and the material to be sampled (including its topsize, surface moisture content, and hardness or friability). A site visit is often required. This essay cannot cover all aspects of MCSS design for a specific system, but the MCSS design should meet the following general requirements:

- The requirements of the pertinent international standard, e.g., ASTM International or ISO, must be met.
- Opening widths (or heights) of cutters, conveyors, and chutes must be at least 2.5 times the topsize of the material.
- Chutework must have angles that are greater than the angle of repose of the material.
- There must be no choke points in conveyors and chutes.
- The MCSS must be as compact as possible.
- The MCSS must be as airtight as possible.
- The MCSS must have access doors, which can be used to observe the system's performance, e.g., allowing verification that the cutters are cutting the entire stream of material, are appropriately sized and shaped, are moving at an appropriate speed, and are not plugged.
- The materials used to make the MCSS must be resistant to the material being sampled.

PERFORMANCE / BIAS TESTING

Conceptually, a performance test is a simple comparison of the material extracted by a MCSS to the material from which it was extracted. In practice, the performance test is complicated by the existence of various statistical models, experimental designs, and interpretive techniques. This short essay will not attempt to discuss the various

options for bias testing, but it is fortunate that ASTM International, ISO, and other international standards bodies have documented and discussed various bias testing techniques for MCSSs. The following standards are recommended for reference:

ASTM D6518-01, Standard Practice for Bias Testing a Mechanical Coal Sampling System.

ISO 13909-8:2001, Hard coal and coke - Mechanical sampling - Part 8: Methods of testing for bias.

During a bias test, the final MCSS sample is usually compared to a reference sample, typically a stopped-belt sample.

A bias test can be conducted to demonstrate that the MCSS is suitable for use, as a provision for paying the MCSS manufacturer for its installation, or as part of an ongoing quality assurance program.

A bias test is usually preceded by a critical inspection in order to locate obvious areas that need correction before the bias test is conducted. There is no reason to perform a bias test upon (or, for that matter, to operate) a system that has obvious faults that may lead to collection of biased samples.

ONGOING QUALITY ASSURANCE

Whenever a MCSS is put into service or bias tested, the assumption often made is that the MCSS will continue to perform in the same manner as it was performing on the day of the installation or bias test. This is a dangerous assumption to make. MCSSs, being mechanical, are subject to wear, require maintenance, and need periodic verifications of their continued capability to operate as designed. It is most definitely a misnomer to refer to a MCSS as an "automatic" sampling system. There is nothing automatic about them, except that they will automatically produce a poor sample if left unintended and poorly maintained.

Once put into service and shown to

be capable, the MCSS must undergo frequent surveillance to monitor and control its performance, demonstrating that the device is performing consistently from one day to the next. Commonly accepted methods for monitoring and controlling ongoing MCSS performance include periodic critical inspections and the use of Statistical Process Control (SPC) charts.

CRITICAL INSPECTIONS OF MCSSS

Every MCSS is different - MCSSs can be designed to sample different materials; MCSSs can be operated differently, e.g., time- or mass-based; MCSSs can be constructed using different components, e.g., roll crushers or hammermills, vibratory feeders or belt feeders, etc.; and MCSSs can sample different lot sizes, topsizes, etc. Therefore, it is not possible to provide a primer on critically inspecting MCSSs that will work in every case. Instead, the following general requirements are offered:

- The inspector performing the inspection must be knowledgeable and experienced.
- Records must be made of each inspection.
- Where required, corrective or preventive action requests must be prepared to remedy inspection findings.
- As necessary, maintenance requests must be issued.
- Follow-up is always required to ascertain that the corrective or preventive action or maintenance request has been completed and that the action is effective in correcting the problem identified.

Measurements are made of cutter opening widths, speeds, and period and records are reviewed for feed rates, lot sizes, etc. The theoretical extraction ratio is determined and compared to the actual extraction ratio. If the two values do not agree within 10%, there may be reason to question the measured values or the functionality of the MCSS.

SPC MONITORING AND CONTROL OF MCSSS

SPC charts, in conjunction with periodic critical inspections, are used to give

assurance that the same conditions as existed when the MCSS was installed or bias tested actually do prevail throughout the ongoing operation of the MCSS. Where there are no changes to the MCSS operating parameters and to the extraction ratio (as demonstrated by the SPC charts for individuals and moving range), it is reasonable to assume that there would be no fundamental change in the operating or bias condition of the MCSS.

Where there is an excursion beyond an action limit, an investigation for the cause of the excursion is conducted.

Various other means of plotting the MCSS extraction ratio are possible.

- A plot of [actual extraction ratio / theoretical extraction ratio] “bounces” around 1.00.
- A plot of the coefficient of variation, a confounding of the two fundamental distribution characteristics of mean (center) and standard deviation (spread), in which the standard deviation is divided by the mean and multiplied by 100%, is often determined on the basis of twenty rolling data points.

However, plotting and monitoring the SPC charts for individuals and moving range allows one to monitor and control the two fundamental characteristics of any process distribution - its center and its range. The process center and the process spread for the “mass of final sample per 1,000 tons sampled” are determined routinely and plotted on SPC charts, which are used to monitor and to control the performance of the MCSS.

The “mass of final sample” can be in pounds or kilograms and “tons” can be metric tons or short tons. In which ever case, carry out calculations to produce values that are significant, yet sensitive to changes in MCSS performance. Remember that a change in extraction ratio can be due to a change in performance of the MCSS or due to a change in the performance of one of the measurement systems - the balance used to weigh the final sample or the belt scales or draft survey used to determine the tons sampled. If your measurements are too insensitive, a

different balance may be needed for weighing the final sample mass.

MANUAL SAMPLING

Manual sampling can also be monitored and controlled by use of several activities:

1. Tally the number of increments collected from each lot of coal.
2. Weigh the gross sample collected from each lot of coal.
3. Calculate the mass collected per increment and compare that mass to the minimum mass to be collected per increment for a material of that topsize, based upon relevant standards
4. Compare the number of collected increments to the minimum number to be collected according to pertinent standards.
5. Audit the manual sampling program to be sure the increments are collected from appropriate locations; that the proper type / dimensions of sampling device are used; that samples are properly identified; sealed, and protected from possible contamination; etc.
6. Train and retrain samplers and inspectors periodically.

SAMPLE PREPARATION

Similarly, if a sample is improperly prepared, the resultant analysis may not accurately reflect the true nature of the lot from which the gross sample had been collected.

1. It is important to audit sample preparation protocols and methods, including equipment design, cleaning of equipment between samples, proper use of equipment, training of technicians, etc.
2. Technicians can be trained and retrained periodically.
3. Retained / referee / sample splits can be weighed and compared to the appropriate mass required for that topsize, according to the pertinent standards.
4. Samples can be checked for identification, integrity, and storage requirements.

LABORATORY ANALYSIS

The gross calorific value (GCV) of coal used for steam generation must be determined accurately and precisely to ensure that the appropriate value is assigned to the cargo and to determine steam plant efficiency and heat rate.

The estimate of the gross calorific value (GCV) of a coal sample in the laboratory depends upon several major groups of factors, usually grouped, e.g., as following:

- The material itself, its heterogeneity or homogeneity
- The method used to determine the GCV, e.g., ASTM D1989; ASTM D2015; ASTM D5865; or ISO 1928
- The machine used to determine the GCV, e.g., Leco AC300; Leco AC350; Parr 1241; Parr 1261; Parr 1271; Parr 1281; or Toshniwal or Raddhani Instruments
- The manpower employed, e.g., the level of training, understanding, knowledge, and skill of the analyst
- The physical environment, e.g., is the laboratory hot or cold; is air conditioning or heat blowing directly onto the calorimeter or the thermometer/ thermistor; does the temperature change from day to night, from morning to afternoon; etc.
- The managerial environment, i.e., the quality management system set up by Management to monitor and control the other factors

LABORATORY PROFICIENCY TESTING

One of the best means to monitor / control laboratory testing is through the use of laboratory proficiency testing programs. Such programs are required by ISO 17025:1999.

RISK MINIMIZATION STRATEGIES

Several strategies can be employed to minimize the risk associated with accepting the results of sampling and testing:

THE PLANNING STAGE:

- Be sure the client and the inspector understand 0.25 what is needed and

why the test is to be done.

- If something cannot be accomplished, e.g. taking a proper sample at a specific location, inform the client.
- Be sure the client and inspector understand and agree upon what methods and equipment are to be used.
- State the risk associated with different techniques and methods.
- Explain to the client the benefits of performing quality work, including replicate sampling and analysis; once the sampling protocols are agreed upon and the analytical method specified, the client must accept the risk cause by chaos.
- Specify that the same sampling, preparation, and testing methods be used at both ends of a transaction

DURING SAMPLING

- Sample in smaller lots.
- Collect more than the minimum number of increments.
- Don't limit the mass of the final sample just to make the final sample easier to handle.
- Use experienced, trained, and skilled samplers and inspectors.

DURING SAMPLE PREPARATION

- Use experienced, trained, and skilled technicians.
- Do not remove a head split or portion of the sample to determine characteristics that will also be determined upon fractions of the remainder of the sample.

DURING TESTING

- Do analyses in at least duplicate; report the average of all determinations.
- Analyze control and calibration samples for every batch or series of tests.
- Require / provide all test results at both ends of a transaction on the same basis (e.g., as-received or dry).

SUMMARY

The proper sampling of a material is paramount in determining the value of a cargo. Risk associated with inaccurate evaluations of cargo is managed by selecting the proper MCSS; installing, operating, and maintaining the MCSS in a proper fashion; and verifying ongoing performance of the MCSS by bias testing, critical inspections, and SPC charting.

Risk management is an important component of any MCSS quality assurance program and must be assigned to a group that is independent of operations, is experienced, and is knowledgeable about MCSS design, operation, and maintenance.

In addition to proper management of the MCSS, risk can be further managed by the selection of an appropriate and reasonable sub-lot size, analysis of sub-lot samples in at least duplicate, and the reporting of weight-averaged analyses (where appropriate, as some parameters should be tested only on a physical composite.)

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