QUANTIFICATION OF COAL RECEIVED: A RESOLVED PROBLEM?[1]

Evaluation of coal measurement methods used today

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RESUMO

Como é do conhecimento da indústria da siderurgia e outras, o carvão é uns dos principais insumos das fábricas de ferro gusa, ferro silicio e outras matérias de exportação ou consumo interno. Por este motivo, sua adequada quantificação se torna um tema relevante.

O carvão vegetal, independente do seu estado, é um material difícil de quantificar corretamente resultando daí, problemas ao longo de toda a sua cadeia de fornecimento e também para o processo de produção. Prova material disto, é a grande vontade das empresas de reduzir a mão de obra no processo de medição do volume de carvão eliminando assim a forma de medição comum, a qual é considerada pouco confiável e responsável por gerar problemas entre fornecedores e compradores.

O objetivo deste trabalho é avaliar e definir os critérios para uma boa medição do carvão. No final, que podemos esperar de um bom método de medição?

A seguir serão revisados os diferentes métodos que existem no mundo para quantificar y dar valor ao carvão recebido considerando a descrição técnica e o suporte científico, destacando além disto, as vantagens, desvantagens e implicações econômicas de cada método.

SUMMARY

As is well known in the iron and steel industry, coal is the main raw material in cast iron plants. Thus, measuring the coal accurately is important.

Regardless of its state, it is difficult to measure coal correctly and the imprecise measurements create problems throughout the supply chain and production process. Thus, companies want to reduce the manpower used in the volume measurement process, thereby eliminating the most common measurement method, which is considered unreliable and also responsible for producing problems between suppliers and buyers.

The objective is to evaluate and define the criteria for measuring coal correctly. What can we expect of a good measurement method? The methods that exist in the world to measure and determine the value of coal received will be reviewed, considering their technical description and their scientific support and emphasizing the advantages, disadvantages, and economic implications of each method.

Palavras-Chave: Medição, carvão vegetal, volume, precisão.

Key Words: Measurement, coal, volume, accuracy.

[1] 3rd International Meeting on Ironmaking; 22-26 September 2008; São Luis City Maranhão State Brazil

1. INTRODUCTION

1.1. What is the problem?

Coal is the main raw material of iron processing plants. It can represent more than 70% of a plant's costs. As coal is difficult to measure, conflicts regarding the precision of the measurements begin during the intake process and continue throughout the supply chain (ex: conveyor belts, inventory, silos, etc.).

"Trade has as its foundation the measurement of quantity. The unit of quantity must be objective, reproducible, easily and cost-effectively determined, and fair to both the buyer and the seller" (Morkel, 1998).

The global debate within the steel and iron industry with respect to which is the better unit of quantity has a long history. Today 90% of the coal that enters processing plants is quantified by volume. This measurement is not easy to implement nor is it reproducible, as it is subject to manual error and subjectivity. It is also neither recordable nor auditable.

Furthermore, it is important to mention the specific situation of an important market like Brazil's. The volume measurement system, which has been around since colonial times, utilizes either a train car system or manual measurement with a ruler. These systems are subject to manual error and high costs.

So, what are the alternatives?

This document reviews the alternatives, exploring the potential of each, carrying out measurement tests, and analyzing the advantages and disadvantages of the different coal volume measurement methods.

1.2. Families of the ways that coal is quantified

According to the study performed, the families are separated in the following manner:

- Measurement and payment by weight
- Measurement by volume (m^3)
    - Direct measurement
    - Laser measurement of coal loads on trucks
    - Indirect measurement of number of full coal carts

2. MEASUREMENT AND PAYMENT BY WEIGHT

Coal measurement by mass is a little-used method to determine the quantity of coal in plants in the Brazilian production regions of Maranhão and Minas Gerais. The benefit of this method is that it has a low operational cost; it does not require much manual labor; and it is objective. Mass can be determined in the following ways:

a) Equipment

- Weighbridge

Weighbridges, typically static and installed in the plant's entrance, weigh the total weight of the truck plus the load (gross mass). After unloading the truck, the truck is re-weighed to get the truck's empty mass (tare mass) and the load's weight is

calculated by subtracting the empty mass from the full mass. The weights are exact and the weighbridges must be calibrated regularly.

- Truck platform scale

Platform scales: The platform scale is on the truck and weighs the weight of the load being transported by the truck. Three types exist; load cells, pressure transducers, and air bags. The load cells are the most accurate with an error of less than 1%.

Loader scales: The loader scale, generally a load cell on the arm of the vehicle, measures the mass of each load that is placed on the truck and then calculates the total truck load. Usually the error is between 3-5% and recent technological advancements may improve this accuracy.

b) Sampling necessary for payment

Some plants that receive coal by weight feel obligated to do load sampling in order to pay fairly. Sampling of the following is done:

- Moisture content
- Proportion of chippings
- Apparent density

Moisture content

Fresh coal that has recently come out of the oven contains very little moisture, generally less than 1%. Moisture absorption from the air, even without rain, is quick. Moisture content from air absorption can reach 5-10%, even for burnt charcoal. When coal has not been burned correctly or when the acetic acids and soluble tar have been taken back in by the charcoal due to the rain, as can happen when burning in holes or earth kilns, the coal's hygroscopicity increases and its natural moisture content can reach 15% or more. Moisture is an adulterator that can lower the charcoal's calorific value. When coal is sold by weight, dishonest vendors often keep the coal's moisture content elevated by wetting it. The added water does not change the charcoal's volume or appearance. For this reason, loose coal buyers prefer to buy by volume (m^3) or by weight with laboratory tests to determine the moisture content and to adjust the price.

It is virtually impossible for the charcoal not to get wet when it is raining during the trip to the market, but storing the coal under a dry roof is a good practice, even if the coal is purchased by volume, since the water evaporates in the combustion and represents a direct loss of calorific power. This happens because water in vapor form rarely condenses and thus it rarely releases the heat that it contains onto the object being warmed in the oven.

Quality specifications generally limit moisture content to 5-15% of the charcoal gross weight. Moisture content is expressed as a percentage of the initial moisture weight and it is calculated by drying a sample of the charcoal in an oven.

Charcoal with a high moisture content (10% or more) tends to crumble when it is heated in the foundry and produces powdered coal, which is not desirable in iron production. If more than 8% of the load is powdered coal, then the supplier is punished in the final payment. This measurement is based on a sampling of 5% or less of the load, thus it is irreproducible.

The presence of water in coal creates an additional problem during storage. The water causes weathering of the coal, due to the changes in the water's volume as it turns from solid to liquid; this tears offs small pieces of the coal, falsifying the grading.

This water also can attack the impurities of the coal, producing substances that degrade the coal.

Density

The density of coal is difficult to measure. There are various types of density:

- *Loose density or mass density*: It is the weight of all of the carbon pieces in kg/m³, including the empty spaces between them. This unit is important for the storage of the coal and for its use in coke ovens.
- *Load density or stack density*: This unit depends on the type of coal, its size, and its moisture content. This unit is used when the coal is stored in a coke retort.
- *Specific apparent weight*: This is the specific weight of a piece of coal in its natural state (pores, moisture content, and mineral material included).
- *Real specific weight*: The weight of a carbon substance without pores and without moisture, but including the mineral material that it contains.
- *Specific unitary weight*: This unit is the same as real specific weight, but also excluding the mineral material, i.e. the ashes.

To illustrate the variety of compositions that can be found in commercial charcoal, the table below lists the compositions of samples taken randomly from different types of wood and carbonization methods. In general, all types of wood and carbonization methods can produce charcoal that fit within commercial limits.

Especies leñosas	Production method	Moisture content %	Ashes %	Volatile material	Fixed carbon	Apparent density Kg/m3		Gross calorific value kj/kg - dry oven
						Gross	Pulverized	
Dakama	Hole	7.5	1.4	16.9	74.2	314	708	32,410
Wallaba	"	6.9	1.3	14.7	77.1	261	563	35,580
Kautaballi	"	6.6	3.0	24.8	65.6	290	596	29,990
Mix of tropical broadleaf species	"	5.4	8.9	17.1	68.6			
"	"	5.4	1.2	23.6	69.8			
Wallaba	Earth kiln	5.9	1.3	8.5	84.2			
"	"	5.8	0.7	46.0	47.6			
Oak	Metallic portable oven	3.5	2.1	13.3	81.1			32,500
Sydney bluegum	Retort	5.1	2.6	25.8	66.8			

Charcoal analysis ([2])

The next table shows the variations in composition of charcoal found in the coal oven of a large iron plant in Minas Gerais, Brazil. All of this charcoal was produced using brick beehive ovens. The wood used was either mixed species from a natural forest or eucalyptus from a plantation.

[2] Source: Simple Methods for Producing Charcoal – FAO, 1983.

Chemical and physical composition of charcoal – dry weight	Variations		Average annually	Charcoal considered good or excellent
	Max	Min		
Fixed carbon	80%	60%	70%	75 - 80%
Ashes	10%	3%	5%	3 - 4%
Volatile substance	26%	15%	25%	20 - 25%
Apparent density (Kg/m3)	330	200	260	250 - 300
Dry apparent density	270	180	235	230 - 270
Average size received (mm)	60	10	35	20 - 50
Powdered coal (-6,35mm)	22%	10%	15%	10% max
Moisture content	25%	5%	10%	10% max

Characteristics of charcoal for industrial ovens in Brazil

The variations and the annual averages refer to charcoal used by Belgo Mineira, 40% of which is eucalyptus coal produced in Belgo Mineira ovens and 60% of which is heterogenous natural wood produced in privately-operated ovens. The coal considered “good or excellent” refers to the coal produced in Belgo-Mineira ovens with eucalyptus wood.

c) System advantages and disadvantages

- Theoretically

The greatest disadvantage is that the mass of the same load changes considerably. This is due to moisture content variation and variation in the coal’s density from the moment that it is loaded, or from the moment that it is dried, until it is received at the plant. For example, the density of coal, depending on the type of wood, can vary between 1 and 1.8. Coal’s density is directly related to its calorific power.

- Operationally

The advantage of measuring wood by mass is that it is quick, easy, and objective. The use of a scale to measure mass is common. Scales are becoming more popular, but only as administrative instruments and not to determine payment.

Measurement and payment based on weight create a perverse incentive for suppliers to deliver coal with a greater moisture content and, therefore, a lower volume due to transportation limitations.

Sampling in order to calculate a fair payment is a slow process and generally increases transport costs. Also, there is always the uncertainty as to whether the sampling was representative of the whole load, since a small error can translate into a difference in thousands of dollars.

As coal is consumed by volume and received by weight, there is no certainty with regards to the quantity in inventory (due to the moisture content variation), thus stock levels must be kept high and the production yield is never accurately known.

d) Discussion

In summary, the quantity of water as well as the density of the coal can vary between suppliers and even from the same supplier, which obligates the buyer to have a database of important information in order to keep track of all of the necessary variables and thus be able to pay the suppliers fairly.

The variation creates a perverse incentive for suppliers to deliver coal with a greater moisture content, which generates conflicts between the buyers and suppliers.

On the other hand, the coal enters into production by volume, which creates reconciliation problems within the supply and production chain. This difference creates a constant conflict between coal costs based on weight and coal consumption based on volume.

The weight and the density vary according to moisture content, age, species, geographical location, time of year, and environmental conditions, among others. These factors are uncontrollable and unmeasurable in the plant, which means that neither the supplier nor the buyer can create a fair price structure.

Weight is objective, easy to measure, and low in cost. However, it is not reproducible nor is it fair.

3. MEASUREMENT AND PAYMENT BY VOLUME

Approximately 70% of the charcoal produced in Minas Gerais, Brazil, is transported by truck. This method of transportation is expensive, but it is flexible and quick and the charcoal can be moved to the iron plants immediately after the drying process. Another benefit is that since the load does not move around much during transportation in the truck, little powdered coal is produced.

The majority of small plants that produce cast iron do not have connections to the railroad and thus they depend exclusively on truck transportation. Trucks can reach isolated ovens, along bad roads.

Despite State regulations about the maximum load size (48 m^3 capacity), some companies use 60 m^3 trailers. However, these trailers cannot operate on bad roads and they have a tendency to tip over. Transport distances can reach 1,000km.

3.1. Payment by volume: direct measurement

In the plants where coal volume is measured directly, there are two categories:

1. Measurement of coal in sacks
2. Measurement of loose coal

3.1.1. Manual measurement of coal in sacks

Many truckers prefer to carry charcoal in burlap sacks (approximately 25kg/sack or 11m^3/sack) so that they can use general-load trucks and bring back other merchandise on the return trip. Coal in sacks takes up more space than loose coal, which settles more during transport and loses between 2 - 5% of its volume. However, trucks with sacks have a higher tendency to flip over than trucks carrying loose coal and sacks must be unloaded by hand.

Trucks loaded with sacks have a peculiar shape because the bottom of the truck is filled with loose coal and then the sacks are loaded on top in such a way that the load settles and pushes together during transport so as to avoid accidents. The loads are thus conical, wider in the top part (see pictures below). Sack loads can easily exceed 4.5m in height.

Types of coal loads in sacks - Brazil

For the measurement process, the frame volume of the sack load is measured. Operators measure the width, length, and height of the load. The height is measured at two or four lateral points along the truck without a defined criteria. The width is measured at the base and at the top, which means that a second operator has to get on top of the load. The length of the truck is measured along the base. The measurements are performed manually with a metric ruler and they are noted manually as well. This type of measurement is slow, risky, inaccurate, and requires a lot of manual labor.

Frame volume measurement of coal in sacks – Brazil

3.1.2. Manual measurement of loose coal

Trucks that carry loose coal have higher sides, up to 4.5m. The frame volume of the coal container is measured manually with a metric ruler. The height is measured from the load to the top of the container. On average they take 4-8 measurements per truck and an average height is calculated. As the truck's dimensions are known, the volume of the load can be calculated by subtracting the empty part of the truck from the total truck volume. This measurement assumes that the walls of the trucks are perfectly parallel, which is not the reality.

Loose coal loads - Brazil

Manual volume measurement of loose coal - Brazil

According to studies in Nueva Aldea, Arauco (Chile) of the frame volume of wood loads stacked like coal sack loads on trucks, the percentage error of these volume measurements was recorded. Similar tests were also done with loose loads. The error depended on the measurement shift, the operator, environmental conditions, the pressure applied by the supplier, and the type of load (high or low). The following results were obtained:

1. During the last hours of the night shifts, there were more problems with the measurements. As there was less supervision, not all of the trucks were measured and the operator would instead “eye” the load and estimate its volume.
2. In difficult environmental conditions such as rain or cold, measurements were more inaccurate.
3. The measurements of one operator versus other operators for the same truck were different. Clearly the measurements were subjective. The difference reached +/- 7%. This difference was even greater for loose coal measurement.
4. The measurements presented greater deviations for high loads (higher than 5m) of which the operator had little visibility and access. For 65m^3 trucks, the deviation reached +/- 5 m3.
5. A very subjective variable is the amount of pressure that the supplier puts on the operator when the incentive is to unload quickly and thus the measurements are careless.
6. The irregularities of the sack loads mean that the dimensions are incorrect. These irregularities can translate into an error of up to 8% when compared to laser measurement.

Coal load irregularities - Brazil

3.1.3. Laser measurement of coal on trucks (in sacks or loose)

The volume of the sack loads on trucks is calculated by measuring its dimensions. The length, height, and width of the pile are measured and multiplied to get the volume of the load.

The volume of loose coal loads in containers is calculated by measuring its height in reference to the top of the container, whether the height of the load is higher or lower than the height of the container. The two heights are then integrated in order to calculate the load volume, which can be either greater or lesser than the container volume.

Laser systems (see images below) for the measurement of coal on trucks process data automatically and quickly, avoiding the subjectivity of manual measurement and the lengthy operational times. The accuracy of these systems for measuring the volume of the coal is greater than 98%.

Coalmeter® system for the volume measurement of loose coal and coal in sacks

Systems like these capture the load on the truck with great accuracy, detecting all of the irregularities on the periphery of the loads regardless of moisture content, atmospheric conditions, time of day, human intervention, and coal density, among other factors. The volume is calculated using mathematical models and image recognition.

a) Advantages and disadvantages of the system

- Theoretically

Systems like these do not require sampling, unloading into carts, or human intervention, as is the case for manual measurement. With laser measurement, all of the trucks that enter the plant are measured individually without subjective operator intervention. As there is no sampling, the inventory error is much smaller.

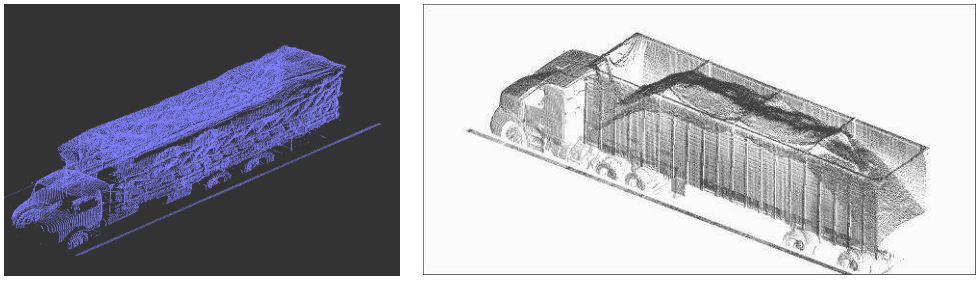
- Operationally

Volume measurement systems for coal loaded on terrestrial transportation, which are based on laser technology, have the advantage of being versatile. The system does not discriminate with regards to the origin of the coal or charcoal or the way in which it is being shipped (in sacks or loose).

These systems provide a back-up of all images and measurement data for each truck that enters the plant and they offer an auditing or consulting system, which can be accessed by the supplier or by the buyer. Variables such as these make the system transparent and thus purchase or commercial transaction is fairer for the parties involved (see images below).

The great advantage of these systems is that they offer 100% automatic measurements, which reduces operator intervention in the coal intake process, ensuring that the process will be objective and free of fraud.

For plants with a high truck flow, systems like these are highly useful, as the time needed to measure each truck does not exceed 3 minutes.



3D images of loose coal loads and sack coal loads on trucks

3.2. Payment by volume: Indirect measurement of number of full coal carts

a) Operation and equipment

The coal is emptied from the sacks into coal carts that have a known volume (between 8 and 20 m^3). The carts are filled and they are leveled off manually while the coal is being unloaded (see first picture below). The total volume of a truck equals the number of carts filled multiplied by the volume of each cart.

Measurement and leveling process.

b) System advantages and disadvantages

The advantage to this system is that volume is measured, which creates more consistency throughout the production chain. The measurement process is easy, but it is not quick since the measurement can only be done once all of the carts have been filled, one-by-one.

The disadvantage is that manual labor is required for the entire unloading process, the leveling of each cart, the movement of the coal to the silo or oven, etc. Also, employers with ISO norms must invest in protective wear and in the health of the operators since the cart-filling process usually occurs in a suspended-dust environment. These mills must buy masks, gloves, and appropriate clothing for the operators. Lastly, the mechanical handling of the loading and unloading of the sacks of coal to and from the carts increases the breakage of the coal and the proportion of powdered coal.

b) Discussion

Stereo volume is used as a measurement unit for coal commercialization mostly because it is practical and objective in field conditions. The disadvantage to using frame volume is that the solid volume can vary according to the arrangement of the load, which can create a significant percentage error when conversion factors are used. The accuracy of the volume estimation increases in relation to the orderliness of the load arrangement.

Given that many elements influence the variability of frame volume, it is inevitable that conversion factors always create errors. These errors can be reduced or eliminated with an adjusted frame volume measurement that is objective, automatic, and accurate.

4. GENERAL DISCUSSION

This table compares the different coal measurement methods available in terms of:

- Accuracy
- Cost
- Operational difficulty
- Use

Method			Accuracy	Cost	Difficulty	Use
Volume	Direct Measurement	Manual Measurement	L	H	M	W
		Laser scanning	H	L	L	Li
	Indirect Measurement	Counting carts and their volume	L – M	H	H	I
Weight		Weight	M -H	M	L	Li

L = Low M = Medium H = High W = Widespread Li = Limited I = Isolated E= Experimental

Comparison of the methods used to quantify coal

Generally, the more accurate the method, the more costly the measurement. Nevertheless, the exceptions include measuring large amounts by weight, which reduces costs. This method is easy, but it has limitations and also an incentive that is not in the plant's best interest. Paying by weight creates the perverse incentive to deliver coal with a higher moisture content and not necessarily denser. The density variations cause uncertainty with regards to inventory levels and losses.

By paying for coal by volume, the plant can maximize the loads that the trucks carry as there is an incentive to deliver dry coal, and thus the transports costs are minimized. Inventory levels will be recorded in volume and thus will not be affected by the moisture content fluctuations. However, as the plant will not be paying for water, it will not feel obliged to do sampling and to calculate the different variables for each truck in order to pay suppliers fairly.

Manual volume measurement is not automatic and thus requires costly manual labor for the measurement process as well as for the data registry.

5. CONCLUSIONS

In order to determine the advantages and disadvantages of different types of coal volume-measurement systems, it is necessary to keep in mind the basic criteria that rank one system higher than another.

After studying the different measurement systems and the users' perceptions of the systems, the following main criteria were determined to be the basis of a "good" measurement system:

Precision and repeatability are important to the raw material payment process. High precision and good repeatability instill confidence in both the supplier and the seller. Repeatability is classified as "good" if the measurement is reproducible during all environmental or labor conditions, thus always delivering the same result.

Sampling does not constitute a "good" method due to the large variation of samples. Clients seek a direct measurement, in which 100% of the loads are measured without sampling or conversion factors.

Fair measurement is ethically sought out to avoid conflicts with suppliers.

Additional important measurement process criteria are the speed, the degree to which the system is automatic, and the level of human intervention. Ideally, the measurement is quick, automatic, and does not involve any human intervention.

Finally, the most vital point for any purchasing process is the registry of the measurements. Thus, clients seek measurement systems that are auditable, in which measurements are stored not only for accounting reasons, but also in order to better manage inventory and to create transparency with the suppliers.

To summarize the current measurement systems, volume measurement on carts is limited almost exclusively to small plants. This measurement tends to be the most expensive due to the high manual labor and the maintenance costs required.

Payment based on weight is not an ideal system as coal moisture content variation creates inventory management problems. Testing of moisture content is a costly investment for plants and the sampling for the tests is not representative.

The payment of coal based on volume possesses the great advantage of maintaining an unaltered unit of measurement from the ovens to the final destination. The disadvantages, in some cases, are the time required for the process, the cost, and the versatility. However, volume measurement systems that satisfy all of the above-mentioned criteria do exist. These systems are precise, quick, automatic, involve little human intervention, no sampling, deliver repeatable results, and offer auditing systems for the storage of the measurement results; thus these systems are classified as good measurement systems.

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