Abstract

Reporting tonnages of stockpiled material is a critical operation. Whilst BTI land surveyors routinely utilize a variety of terrestrial equipment and surveying techniques to report stockpile volumes (conventional, tacheometer, Reflex laser total station, GPS device and 3-D scanner), the determination of a stockpile’s density, to derive a tonnage, is not a routine exercise.

This paper examines all kind of solutions available and potentially used for years at BTI agencies.
Biography of the author

Alain Deloye is the Technical Services Manager of BTI since 1996. He has extensive surveying experience in various fields: manual & mechanical, coal training, quantity determinations through hydrostatic and stockpile weighing. He is a member of the French AFNOR M01B committee for standardization, as well as he participates to ISO TC27 groups.

Problem to solve

The problem of determining reliable stockpile mass is well known. Coal or ores are in constant change (compaction, moisture content, and size); often they are globally inaccessible. Thus direct measurements of mass can be subject to systematic and cumulative error. During handling operations in which coal is delivered to stockpiles by barges, railcars or trucks, which are subject to static weighing, stock mass can be well monitored. When material is delivered by conveyors and weighed by dynamic scales, the errors can become problematic.

Common equipment

For volume assessment, BTI is using the last state-of-the-art technology:

GPS system
Plan de marketing pour [Nom du produit]

TRIMBLE total station (TRIMBLE 5300 DR REFLEX)

SPATIAL IMAGING SYSTEM  (TRIMBLE VX)
Technical solutions for bulk density measurements

3-D SCANNER (Maptek / LEICA)

All these topographic devices are connected with AutoCad Map, Trimble and Covadis software for the volume calculation. Due to the high efficiency of this equipment, the high number of points which are measured on the ground, the accuracy of the volume calculation is close to 100%.

The final calculation is based on:

D6542-05 Standard Practice for Tonnage Calculation of Coal in a Stockpile

And refers to [TONNAGE = (VOLUME x BULK DENSITY)]
Common practice for density determination

Specific gravity is commonly determined in a variety of ways:

a) **Nuclear density gauge**

They are two kinds of modern density gauges:

I. **A nuclear depth density probe** which needs drilling the stock for measuring the gravity between gamma source and detector is described in ASTM D 6347. The density should be determined at various depths and, with heterogeneous material, in various locations of the pile.

![Nuclear Depth Density Probe](image1.png)

This can be a very heavy field operation which needs trained teams, official authorization for transporting and using a nuclear source (Cesium 137). Additionally, the representative character of such measurements is doubtful as most of the time, only one drilling is performed. Last but not least, the density gauge should be calibrated (which needs homogeneity of the material) and it becomes hard to calculate a variance without repeating values.

II. **A surface soil density gauge** with a metal probe which be inserted in the material. The detector located in the base of the gauge measures the number of hits by radiated packets of energy.

![Surface Soil Density Gauge](image2.png)

The moisture content of the material could be measured through a second Neutron source (americium / beryllium).
Despite a few testing and some technical articles relating experiences, BTI has performed in the past some industrial testing with a specialized public works company and all tests results were rejected due to poor reliability. We are convinced that this device was able to measure dense material such as asphalt or other road base material, perhaps dense fine iron ores, but for sure not coal. Also, the probe is 20 to 30 cm deep and has no interest for large coal stockpiles.

b) **Q-MASTOR integrated stockpile management**

QMASTOR software, developed in Australia, enables management to plan, record, track, optimize, account, reconcile and report the tonnage, quality and value of bulk materials from mine to point of export or consumption. The system synchronizes operations, logistics, functions using GPS techniques and sophisticated calculation software. It also enables the plant management to receive on-time information as soon as the material is moved with stacker/reclaimer or bulldozers equipped with GPS system connected to the central computer. It also delivers constant Three Dimensional Stockpile Modelling drawing.

BTI has been agent for Q-MASTOR during a few years, before stopping our partnership with the Australian company due to a lack of interest of European customers.

Based on either static or dynamic weighing, Q-MASTOR system avoids measuring the bulk density.

c) **Drilling rig method:**

This method has been used for assessing the quality of various layers on a large pile of material. A few trials have been by BTI for using the tubes extracted after drilling to measure bulk density, but it proved that the coal inside the tubes (carrots) was disturbed and therefore the density was potentially underestimated.

d) **Calculation methods:**
Based on Yu and Standish study (August 1991):

“ESTIMATION OF THE BULK DENSITY OF A COAL STOCKPILE”

This formula is taking into account the size of a stockpile, the staking method, the moisture content and the physical properties of a coal. YU & Standish have developed model equations. Their approach looks interesting as they consider the bulk density of a stockpile and not a theoretical bulk density performed at the laboratory. All data necessary to calculate the complete equations are not often available and this is why it will remain so far as a theoretical work.

From the same authors:

“An experimental study of the packing of a coal heap”

e) Standardized methods:

I. AFNOR M03 031 standard

Determination of the bulk density in small dimensions container

II. DIN 51705 standard

Determination for the bulk density of solid fuels

Both methods describe the principles of the usual and empirical testing by weighing a filled container of known volume.

Figure 1 - BTI experiments in China

Figure 2 – BTI experiments in Morocco

This method will not take account of the variation of density caused by compaction.
Sampled material is collected from the relevant stockpile at different locations all around the pile and as deep as possible (according to ISO 18283 Annex B). The sampling tool must not be used on the surface but inside the material to avoid major problems with moisture variation due to air / sun drying or on contrary heavy rain spraying on the surface.

A cubic meter box or half cubic meter box in hard steel is used. Filled with raw material which is not compacted, we obtain a so-called “stowage factor” value. Filled with raw material after heavy compaction in the steel box, we obtain a “compacted” value. Both are considered as extreme values with a minimum and a maximum result for each coal tested.

After weighing data is expressed as follow:

\[
\text{Bulk density} = \frac{\text{Total mass} - \text{Steel box}}{100 - H20} \times \frac{\text{Volume in M3}}{100}
\]
This method has been improved when the coal is thrown from a certain high (see above) into the iron vessel. But once again, it cannot be related to a mechanical compaction with heavy engines and rolls.

f) BTI research works:

I. Penetrometer

Compaction could be estimated through penetrometer tests (Panda variable energy input dynamic cone penetrometer). It will inform usefully on compaction homogeneity and soil hardness control. Using mathematics model, the Panda value could be interpreted as a coefficient for both values obtained above.

II. On-site sampling and weighing material

Best practice is to use a stainless steel cylindrical ‘box’ with a large diameter (for example 110 cm diameter x 50 cm height). The cylinder is then inserted in the coal pile at designated locations after opening and flattening the pile with a bulldozer. The material inside of the cylinder will be collected, weighed and the bulk density calculated with the volume of the geometric device.
Such testing combines the theoretical approach of the standards and the on-site experience of BTI.

After some experiences, BTI has manufactured a cylinder of

- 53 cm high
- 58 cm diameter
- 0.14 m³

For easy manipulation and use (*empty it weighs 40 kg*), the cylinder has been reinforced and is equipped with chains for being extracted easily from the coal pile.

### III. Concerning long term stockpiles

BTI is recommending using the following method:

**Phase 1**

a) Collecting the individual *raw material and compacted bulk density* values for each quality / shipment stored into the pile,
b) Calculating a “weighed” average of the various qualities / shipments inside a pile,
c) The same calculations are made with the moisture content.

Phase 2

d) During the stockpile inventory, samples are collected and tested as described in (e) II above.
e) Information are collected in order to define a compaction factor from 1 to 5.
f) Density and moisture are compared to the initial ‘phase 1’ data using the compaction factor; the variance between both is established and is used for correlating data.
g) If the variance is less than 1.0 for moisture, as determined values are considered as acceptable.
h) If the variance is less than 0.02 for density, as determined values are considered as acceptable.
   In both cases, overestimated values will involve rejection of values.
i) A draft of our report is attached to this document.

Rouen, the 18th September 2012.