Washability Monitor for Coal Utilizing Optical and X-Ray Analysis Techniques

Jan F. Bachmann, Claus C. Bachmann, Michael P. Cipold, Helge B. Wurst
J&C Bachmann GmbH, Bad Wildbad, Germany
Mel J. Laurila
Quality Control, Inc., Georgetown, KY, USA
Hauke Springer
Springer New Technologies GmbH, Bad Wildbad, Germany

ABSTRACT: In coal washability, the objective is to establish the set of maximum possible separation performance criteria for a given coal feed. The method of choice for this has been the conventional sink-float analysis. Time, cost and safety aspects of the sink-float method have prompted the search for a new approach for establishing separation performance criteria, especially as performance levels of separator plants can be maximized if reliable information based on an analysis of washability in conjunction with particle size distribution, ash and elemental constituency becomes readily available.

The new method to establish washability and associated performance information utilizes at least two measurement technologies concurrently: x-ray transmission, image processing, and, optionally, XRF elemental analysis of each coal particle. The value of the collected data increases considerably if the washability data were additionally available in time to be considered in the control of the process plant. The incorporation of an automated washability monitor giving near real-time data would impinge positively on the profitability of the plant operation.

Tests performed with the prototype utilizing optical and X-ray analysis methods are encouraging.

Washability

The washability of coal or minerals is expressed by a curve or graph showing the results of a series of float-and-sink tests. A number of these curves are drawn to illustrate different conditions or variables, usually on the same axes, thus presenting the information on one sheet of paper. Washability curves are essential when designing a new coal or mineral preparation plants. There are four main types of washability curves: characteristic ash curve, cumulative float curve, cumulative sink curve, and densimetric or specific gravity curve [1]. The different curves are based on the relation between ash or ore grade, mineral density and particle size distribution.

In determining the washability analysis, the particle density is the underlying feature of all washability curves. Conventionally, the particles were separated into density fractions by immersing them in fluids of a predetermined density, and skimming off those particles that remained afloat in the liquid. The particles remaining afloat thus had a density lower than that of the fluid they were subjected to. The particles that remained at the bottom of the fluid container thus had a higher density higher than that of the fluid. By progressively increasing, for example, the density of the fluid and immersing the remaining particles so as to be able to skim off the next density fraction, the particles would be fractioned into density groups. The liquids used range from aqueous solutions to organic liquids to suspensions. Unfortunately the liquids used for this separation process are often toxic and expensive. It stands to reason that a new method of determining washability is sought.

In addition to density, particle size distribution is also of importance to the topic of washability. Typically, the particle size distribution is based on sieve analyzes. This technique is well introduced and proven in the laboratory. However, the size of a particle is not fully described by the mesh size of a sieve:

- sieve meshes may have different shapes (circular, hexagonal, square)
- particles must not necessarily be cubic or globe size
- long but small particles may pass small meshes.

Using a model which describes the particle size by three measures (length · width · height) it can be stated that the sieve analysis characterizes the particle size by the second largest (equal to the second smallest) of these measures.

Although this method is the viable way for a sieve analysis in the laboratory it may be logical to regard the particle volume instead of the sieve size as the best characteristic feature to describe the size distribution.

Considering the issue around the liquids used in conventional float and sink analysis, as well as the requirement of a better volume determination of particles, this paper introduces a new method of determining washability curves that is suitable for daily use, and is deficient of the disadvantages of the conventional float and sink and sieve method.

The development of a washability monitor for coal particles has to determine at least some of the following characteristics of the coal to be measured:

- washability curve
- particle size distribution
- elemental constituency
- ash

For the development of such a washability analyzer to be of interest to the coal preparation industry the monitor must bring with it at least these advantages:

- It must be relatively fast, reducing the usual manual effort of weeks into hours
- It must be reliable, working with minimal intervention of personnel
- It must work in an on-line fashion, and should demonstrate a high degree of mechanical integration into the process path at the point of measurement.

In order to achieve these goals the developed washability monitor combines optical with radiometric measurement and derives all requested parameters in a nearly real-time analysis.

Volume Determination

Optical distance measurement in the range of 10 – 100 cm is mostly done using lasers. This technique is available for more than ten years and is widely accepted. The basic principle can be seen in figure 1. A laser projects a well focused dot onto a surface. The laser image is then projected by using a lens onto a detector which can be a CCD line or a position sensing device to measure the distance through the lens. The lens which “sees” the dot needs to be mounted at an angle to the surface where the laser dot is projected. The position of the projected laser dot on the detector depends on the distance of the detected object to the detector and on the distance between laser and sensor.

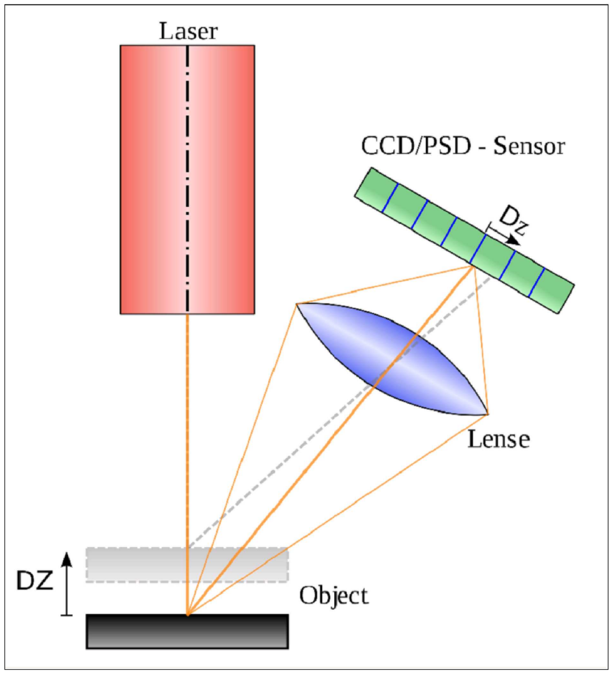

Figure 1. Principle of laser triangulation

Using the one-dimensional approach will give only very little information about each particle on a conveyor belt. In the best case we will get the length and a height profile at one single line of the particle. In the worst case a particle will not be seen at all because it is not exactly centered. If the particle is scanned a second time and the orientation does not match the previous one exactly, the measurement will show a totally different result.

The principle can easily be expanded to a two dimensional measurement by replacing the spot laser by a line laser and the single detector by a camera evaluating the camera data with a high-end computer. Given multiple height lines recorded from a moving particle it is obviously easy to sum up the volume of each particle. Using a standard camera is an economic and easy way to realize the measurement.

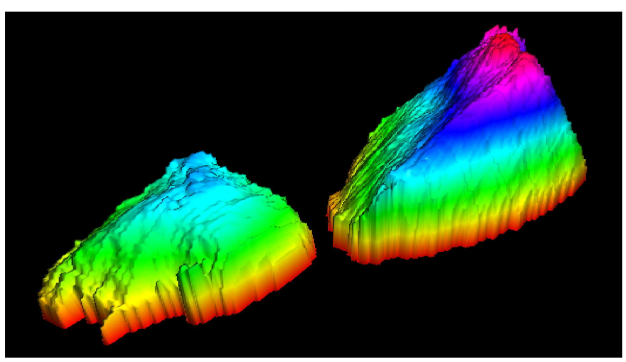

Figure 2. False color display of a scanned particles in 3D

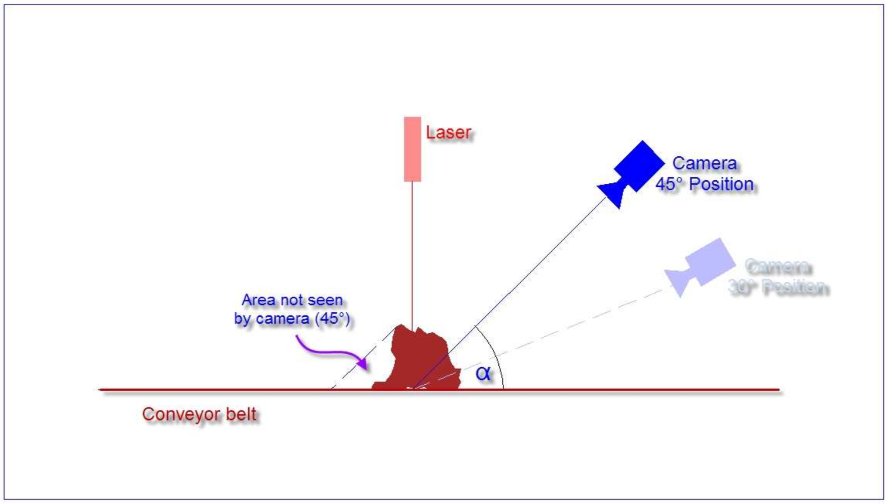

Figure 3. Laser and camera alignment

In order to be able to maximize the amount of particles which are scanned correctly and to see the back sides of each particle a second camera is used mounted on the other side of the laser. The data of the two cameras is then correlated and combined as shown in figure 4. The upper third of the image shows the particle heights as seen by the first camera and the middle third as seen by the second camera. The lower third shows the correlated data without the errors which would result from a single camera.

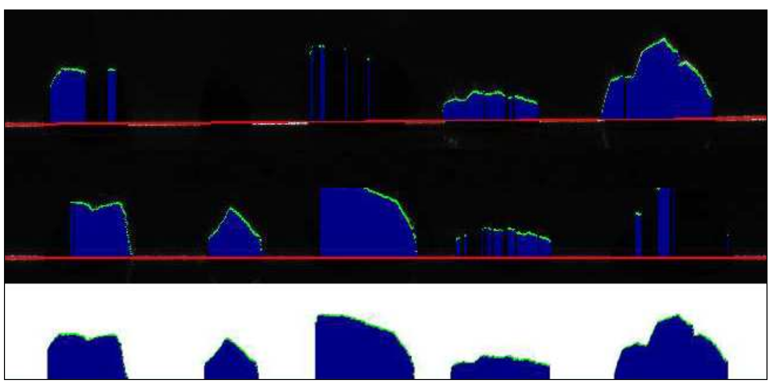

Figure 4. Data combination of two cameras

Weight and Density Determination

The fundamental principles of the application of x-rays for the determination of densities of materials are described by Zou et al (2008). It is stated that x-rays have the ability to penetrate matter and interact with atomic species. The material under investigation is irradiated with x-rays of known incident energy and the attenuated intensity is accounted for by coherent scattering, incoherent scattering and photoelelectric absorption. The absorption law as given in equation 1 shows the relationship between amount of x-ray absorption or transmission and the material density and thickness.

$$I = I_o \cdot e^{-\mu \cdot \rho \cdot d} \quad (1)$$

Where

I_o = incident radiation

I = transmitted radiation
d = absorption path length
μ = absorption coefficient
ρ = product density

By knowing the incident radiation and the constant absorption coefficient in the material and measuring the transmitted radiation using a x-ray line detector the area weight (ρ·d) can be derive trivially. By measuring the absorption path length (see optical measurement) the density results just by dividing the area weight by the amount of material.

Mechanical Setup

The mechanical setup consists of the described optical and radiometric measuring tracks installed on a conveyor belt and a control box which contains the PLC to control the hardware and the computer to do the data analysis. The schematic setup can be seen in figure 5. The two measuring tracks can be combined to be installed at the same part of the belt which was not done in this graph to make it easy to see all components.

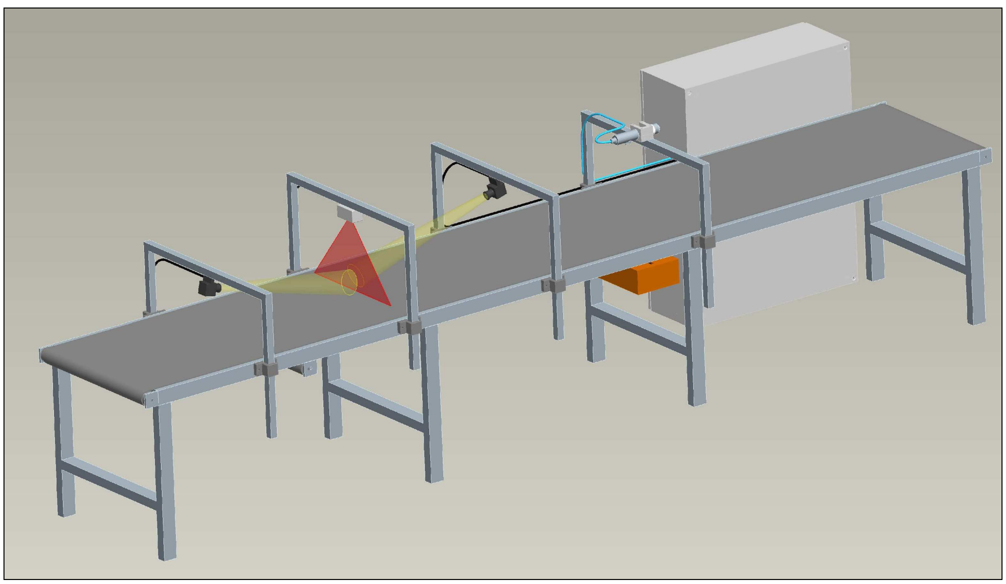

Figure 5. Mechanical setup

The particles are fed onto the belt from the left side and move through the laser (red triangle) where they are recorded by the two cameras (devices mounted before and after the laser). Then the particles move through the x-ray beam and their “shadow” is recorded by the x-ray line sensor which is mounted below the belt (orange). The calculation is done immediately so the particles can optionally be sorted directly behind the X-ray measurement by using a robot arm.

Washability Determination

The software suite RACOON running on the computer in the control box records the height lines from the optical measurement and the so called weight lines from the radiometric measurement. Then the lines are combined to an area image and single particles can be derived from the data. These particle data already contain the volume of each particle as well as it's width, height and length and also the weight. Combining the weight and the volume of a particle will give the density.

These parameters which are available for each single particle are then used to derive the washability curves as well as density and volume distribution.

Measurement Results

The following section shows some results of the device we gathered during intensive tests with coal samples from West Virginia in out laboratory.

After being fed onto the belt by a vibrating feeder the coal particles move through the measuring tracks which are covered in the housing for optimal x-ray shielding.

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Figure 6. Laboratory setup with coal sample

Each particle is scanned and shown in the software overview. All parameters can be looked up in detail for each particle by positioning the cursor on the particle as shown in figure 7. This particle shows optically a uniform shape.

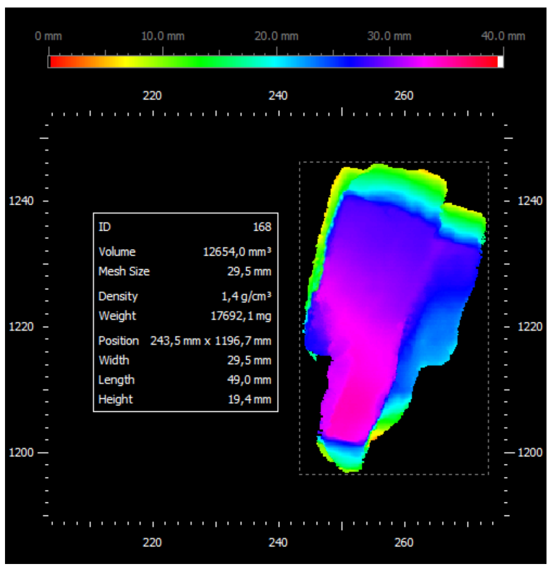

Figure 7. Analyzed coal particle with calculated parameters

Figure 8 shows the corresponding X-ray image of the same particle which illustrates the weight per area in false colors. Lower area weights are shown in red and the higher area weights are shown in yellow and green. This image indicates the different density layers within one coal particle impressively.

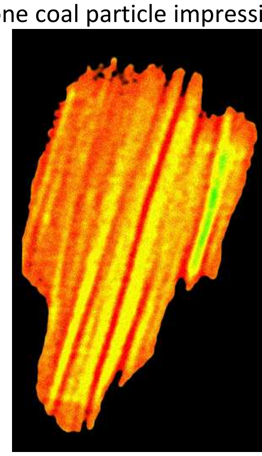

Figure 8. X-ray image of the selected particle

Statistical Evaluation

As the particles run through the machine results graphs are built in real time to illustrate the current parameters over all particles. Figure 9, 10 and 11 show graphs for two different coal samples (red and blue). Figure 9 is the density graph indicating a scatter plot of mass versus volume. It is easy to distinguish the two density classes of the samples even without the colors as they show clear separation.

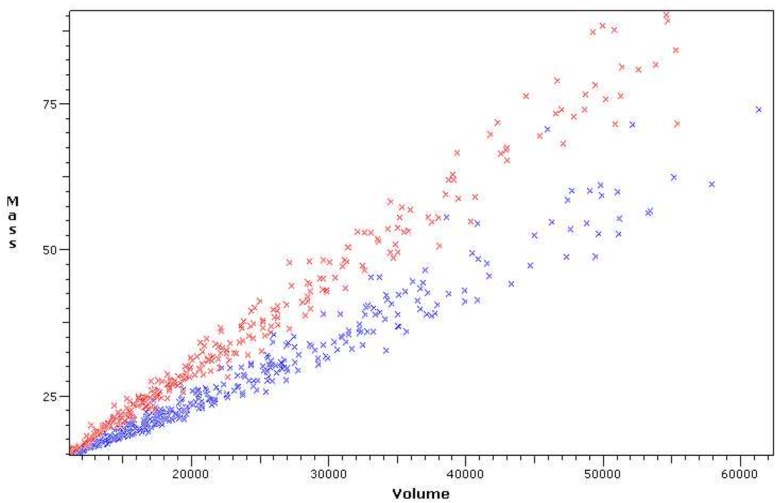

Figure 9. Density graph mass (in g) vs. volume (in mm³) of two different samples

In figure 10 the masses of the density classes are summed up to illustrate the grade of separation which can be achieved.

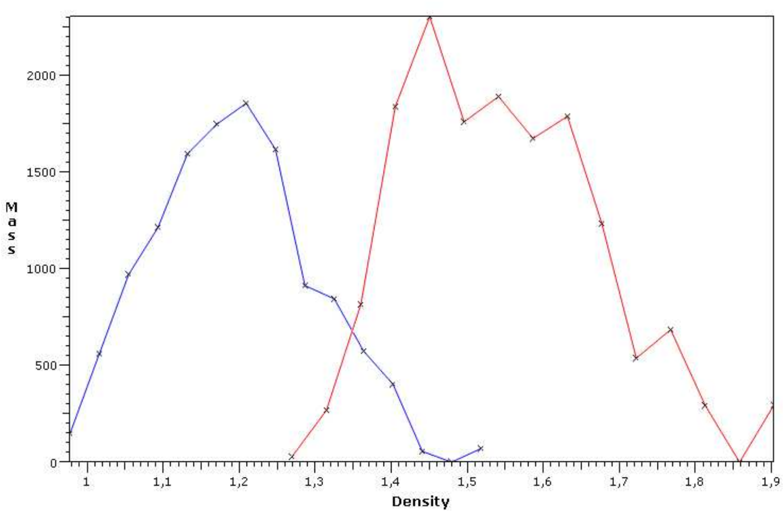

Figure 10. Density distribution for the same two samples

The last figure 11 finally presents the washability curves of these two samples. While the total mass is shown on the vertical axis the horizontal one show the density of the particles.

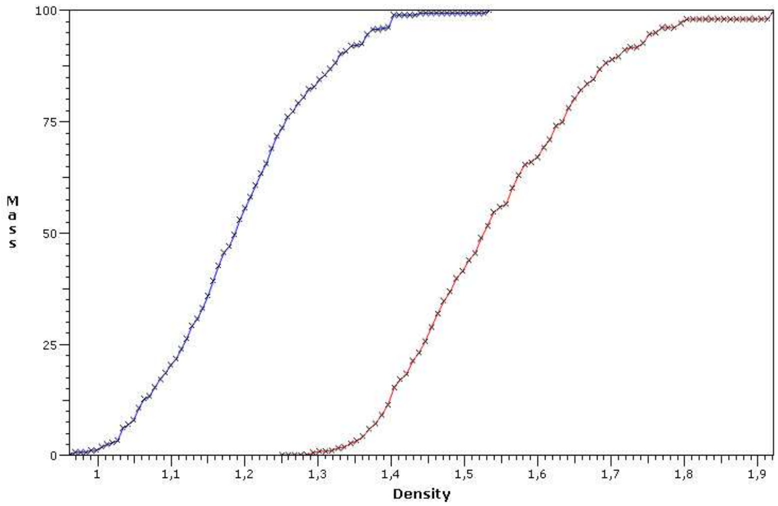

Figure 11. Washability curves with the summed up mass over the density

Conclusion

Although this device is not in regular use in a laboratory it is proven that the highly set goals mentioned in the first section will be achieved with the washability monitor. The next step will be an intense test of the prototype in a coal mine laboratory.

References

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