Bulk material science and improving power plant coal handling

By R. Todd Swinderman, P.E., and Andy Marti

The greatest advancement in the engineering of coal handling systems is the increased use of bulk materials science.

This science is based in the testing and analysis of both the bulk solid and the construction materials that the bulk solids will move on, over, or through. Combined with computer-based engineering and modeling systems, bulk materials science offers improvement for coal handling operations in power plants. Some improvements include helping to manage flow, reduce bottlenecks, reduce dust, spillage, and carryback, extend equipment life, and reduce maintenance expenses – all improving a plant's availability, efficiency, and profitability.

The basic science of basic materials

Bulk Materials Science is an interdisciplinary field centered on determining the properties of bulk materials and applying those properties to various problems in the design of bulk material handling systems and components. This science investigates the relationship between the bulk material(s) with the surfaces it will flow over and the equipment it will flow through.

Since the first conveyor was designed, the basic properties of bulk materials, such as bulk density and angle of repose, have been used to size the system and calculate its power requirements. Modern bulk material science traces its roots to Andrew W. Jenike's work at the University of Utah, which determined the critical dimensions of mass-flow bins, based on the strength of the bulk material under various conditions. The methods developed by Jenike are used to determine the internal strength of bulk solids and the friction between it and the belt or chute. These properties are used to predict the behavior and flow of the bulk solids from silos and storage vessels, and later, with increasing success, through chutes and onto belt conveyors.

Improved testing and computerized engineering now make it possible to improve designs of specific systems to perform as expected with identified materials. Serious errors can be made if a material handling system is designed without determining the appropriate basic and advanced properties of the specific bulk material being stored, conveyed, or otherwise handled.

Many of the basic properties and tests for bulk solids are outlined in the Conveyor Equipment Manufacturers Association (CEMA) Standard 550. The properties most often used (and sometimes misused) in the design of belt conveyor systems are:

- **Bulk density:** Bulk density of a bulk material is the weight per unit of volume kg/m^3 (lb/ft^3), measured when the sample is in a compacted condition. This Vibrated or Settled Density is used with surcharge angle for determining the volume of material conveyed on the belt.

- **Loose bulk density:** Loose bulk density of a bulk material is the weight per unit of volume kg/m^3 (lb/ft^3) measured when the sample is in a loose or non-compacted condition. The loose bulk density must always be used when designing the load zone chutes and the height and width of the skirtboards or the chute may not be able to handle its specified ("design") capacity due to the material's increased volume.
- **Angle of repose:** The angle of repose for bulk materials is the angle between a horizontal line and the sloping line from the top of a freely formed pile of bulk material to the base of the pile. This angle of repose for a given material may vary, depending on how the pile is created, as well as the density, particle shape, size consistency, and moisture content of the material.
- **Surcharge angle:** The surcharge angle is the angle of the load cross section measured by the inclination in degrees to the horizontal. The surcharge angle is useful in conveyor design for determining the profile of the load on the belt for various belt widths and trough angles to calculate the theoretical carrying capacity.
- **Lump or particle size:** The size of a bulk material is described two ways – as the maximum lump size, or as the percent of particles that will pass a series of standard screens (or sieves).

  Size is often listed as the maximum lump width and breadth. A material with a maximum lump width and breadth of 50 mm x 50 mm (2"x2") would be described as 50 mm (2") minus material. This means the largest lump is 50 mm x 50 mm and the rest of the particles are smaller. It is common practice to assume the length of the lump can be as much as three times larger than its width, or in the above example 150 mm (6") long. This information is useful in sizing various components and the width and height of chutes and skirtboards.

  A screen analysis gives the most complete representation of the size of the bulk solid. The particle size distribution is a tabulation of the percent represented in each size range as part of the total sample, usually shown as passing a given screen size and being retained on the next smaller screen. This information is useful for analyzing airflow in chutes, and the potential for the creation of airborne dust.
- **Flow properties:** The basic flow properties of a bulk solid can be derived from shearing the bulk solid (in a device called a shear cell) and measuring the force required. Usually the fines from the bulk solid are tested since they are the portion that changes strength with moisture and pressure and acts as the "glue" that retards flow.

  The shear cell method also is used to measure the friction between the bulk solid and the belt or chute construction materials. For conveyors, the important conditions are the variation in strength with different moisture contents and consolidating pressures. Shear cell tests are particularly time consuming because of the number of tests run at different moisture contents and consolidating pressures.
- **Interface friction:** Two values of friction are important in chute design – the coefficient of friction between the bulk solid and the chute wall, and between the bulk solid and the belt. Bulk solids, particularly the fines, have the ability to cling upside down on horizontal surfaces and exhibit strength, even under negative consolidating forces greater than gravity. The shear force of negative consolidating forces is of particular interest in chute design in determining adhesion and cohesion values.
- **Adhesion:** Adhesion can be thought of as the stickiness of the material to surfaces, such as chutes and belts. Surface condition, moisture, and impurities (such as clay) are the principle variables that affect the level of adhesive stress in a bulk solid. Adhesive stress can be determined from shear cell tests and is very useful in determining the likelihood of the material to stick or cling to surfaces.
- **Cohesion:** Cohesion can be thought of as the ability of the particles to stick to each other. Cohesion in a bulk solid is affected by three conditions: moisture content, electrostatic attraction, and agglomeration. Cohesive stress can be determined from shear cell tests and is very useful in determining how bulk solids will flow.

The application of testing information

So, all this science is a good thing in an empirical, "nice-to-know" sense. But what are the implications for material handling systems and the design of equipment?

Here is what material science can help determine more accurately:

- **Conveyor capacity:** Conveyor capacity, usually expressed as tons per hour, is one of the basic design parameters directly calculated by knowing the density – kg/m^3 or lb/ft^3 – of the bulk material. Most of us are familiar with density as it refers to solid-like steel or concrete – this is called particle density.

  However, in conveyor design, there are several densities to consider that are typically fractions of the material's particle density. Settled Bulk Density is used with

This testing system provides the basis for a variety of testing, including rigidity, tensile strength, and compression. It is used with sophisticated control mechanisms and data acquisition systems, to provide testing capabilities for larger samples, "stronger" materials and accurate results.

the cross-sectional area of the load on a belt to determine the nominal carrying capacity of the conveyor. "Loose Bulk Density" can be as little as half the Settled Bulk Density. This is the state of the material as it is normally carried on the belt.

If a conveyor transfer point is designed using Settled Bulk Density, it will likely plug at less than its rated capacity because the material takes up more room. There is an old saying: "You can't put 10 lbs. in a 5 lb. bucket." In this case the plant is trying to get 10 lbs. of loose material through a space designed for 10 lbs. of condensed material.

At the Center for Innovation, the process simulation area incorporates a three-belt recirculating conveyor loop carrying materials for observation of material flow and component life.

If an inexperienced designer looks in a general engineering handbook for a material's density, the value listed will probably be the particle density. Using the particle density, the inexperienced designer can undersize the conveyor by a factor of two to three. This error will have serious consequences in pluggage, spillage, and the throughput problems it causes for the conveyor system.

- **Chute design:** Chute design is more than a matter of having the correct cross-sectional area based on the Loose Bulk Density. The reliable flow of bulk solids through a chute depends, among other factors, upon the friction between the bulk solid and the chute walls and wear liners. If the friction is too great, the material will slow in its passage through the chute. This decreased flow leads to bottlenecks, buildups, and blockages.

The design of the "new generation" of flow-engineered chutes depends on knowing the properties of the bulk solid in relation to the flow surfaces. Most often, when a handbook value of chute angle based on the angle of repose or surcharge is used, buildups leading to blockages are the result. For example, lignite has a significantly higher coefficient of friction on stainless steel than bituminous coal, but the coefficients of friction are similar when UHMW polyethylene is the liner. Serious flow problems can result from not testing the actual bulk material transported and the actual lining considered for the design.

The data from the testing of the specific coal being used and the specific construction materials — stainless steel or ceramic liners, for example — is critical. It will help predict the flow of the material through the chutes, reduce wear on components, and eliminate the escape of fugitive material like spillage and airborne dust.

Martin Engineering's new research center focuses on improving material handling

Leading edge companies are providing bulk material testing as an option when they design material handling systems and components. Among those leading companies is a small firm located in the cornfields outside rural Neponset, Ill.

Neponset is home to Martin Engineering, a small company, but global supplier of systems and services that make bulk materials handling cleaner, safer, and more productive.

The new Martin Engineering Center for Bulk Materials Handling Innovation holds the promise of improved productivity and profitability for these industrial operations where the clean, efficient handling of bulk materials is a key to the production process.

The Center for Innovation — or CFI, for short — is a $5 million facility designed with the goal of improving bulk material handling through collaboration, innovation, and education.

CFI is housed in a new 22,600 square foot (2,100 square meter) building at Martin Engineering's headquarters in Neponset. Part pure-science research laboratory and part industrial product development center, CFI will collaborate with partners such as corporations, industry associations, and universities, for practical research to solve the common problems in the handling of bulk materials – problems that have plagued industries like coal-fired power generation, mining, cement manufacturing, and aggregate production for years.

These material handling problems include the release of fugitive material, such as dust and spillage, and also hang-ups in material flow. These problems lead to added maintenance expenses and productivity losses, resulting in reduced profitability for the heavy industrial operations.

The new CFI facility now includes a full-time staff of 15, including scientists, engineers, and technicians, all dedicated to advancing the understanding of the behavior of bulk materials and the performance of materials handling systems.

CFI has the scientific instruments and full-scale materials handling equipment to test bulk materials and prototype components under simulated operating conditions. Included in CFI are laboratories for the analysis and testing of characteristics and performance of metals, polymers, and bulk materials, and an environmental lab for accelerated aging.

The labs include the equipment required to do analytical testing of samples of specific bulk materials, including ring and direct shear testers for testing material strength, adhesion, and cohesion, as well as sieves and sieve shakers to determine particle sizes.

The facility's process simulation area features a full-scale recirculating conveyor system for testing both bulk materials and equipment prototypes. The process simulation "loop" is composed of three belt conveyors arranged in a triangle to carry simulated

The direct shear tester will pulls across a confined material under various applied pressures and moisture contents to determine the material's friction, cohesion, and adhesion to a substrate such as a liner material.

materials from one conveyor to the next in a continuous, recirculating stream for observation of material flow and component life. Two of the conveyors are 30" (750 mm) wide; the long leg of the triangle is 48" (1200 mm) wide. One of the conveyors is an air-supported belt conveyor; the other two incorporate conventional idlers.

"This recirculating conveyor system will let Martin Engineering product engineers and material scientists test product prototypes and model the handling characteristics of bulk material cargoes on full-scale material handling equipment," said R. Todd Swinderman, Martin Engineering's Chief Technology officer. "We will be able to work with the specific materials of a customer to develop solutions to their unique material handling problems."

The new research center also will offer education for industry personnel — management, engineering, operations, and maintenance staff — about how material handling systems work and how they can work better. CFI features dedicated training resources, including a state-of-the art, 44-seat training room and a video conference center. The facility also includes an observation deck where visitors can view material and equipment testing underway in the facility's laboratories and on the recirculating conveyor system.

- Compiled by Andy Marti

• **Belt cleaning:** The properties of a bulk solid can be used to predict the nature of the belt cleaning challenge the operation will face. The properties predict how much material will adhere to the belt past the discharge and how changes in conditions — such as an increase in moisture level from a rainstorm — can affect carryback levels and cleaning performance.

Adhesion and cohesion are important properties used in this prediction. Knowing the material's critical moisture content — where its adhesion and cohesion change dramatically — allows a designer to calculate the volume of water needed to reduce the carryback material's strength or to wash the belt.

• **Safety:** Testing a bulk solid for its properties allows the designer to develop safe storage and conveyance for bulk solids. For example, it is well known that flowing bulk solids can create unequal wall pressures on silos. Without testing the specific materials under the expected conditions for storage and haulage, a designer is only guessing at the forces involved. There have been too many instances where a worker has been injured by falling material when trying to remove buildups from a chute. Less catastrophic, but just as damaging to productivity are systems designed using typical or average values to design conveyors. Many a conveyor designed without the specific knowledge of the material properties has failed to deliver its design capacity.

The benefit (or consequence) of material testing: An example

The numerous "varieties" of coal can have very different characteristics. The CEMA 550-2003 publication "Classification and Definitions of Bulk Materials" lists nine different classifications for coal, from $^1/_2$" minus anthracite to run of mine bituminous. This reference lists from 45-60 lb/ft^3 as the loose bulk densities for various coals, with surcharge angles listed from 20-30 degrees.

The 6th edition of CEMA's "Belt Conveyors for Bulk Materials" — commonly called "the CEMA belt book" — gives detailed equations for calculating the capacity of a conveyor based on the trough angle and the surcharge angle. To demonstrate the value of basic material data, let us compare the cross sectional areas found by using the values of two different coals from either end of the published list.

Givens:

- Loose Bulk Density: 45-60 lb/ft^3 (720 to 960 kg/m^3)
- Angle of repose: 30-40 degrees
- Angle of surcharge: 20-30 degrees
- Belt Width: 48" (1,200 mm)
- Trough Angle: 35 degrees
- Edge Distance: Standard CEMA edge distance
- Belt Speed: 500 fpm (2.5 m/s)

The CEMA book, "Belt Conveyors for Bulk Materials," specifies the cross sectional areas. They are:

- 20 degree surcharge angle: 1.804 ft^2 (0.168 m^3)
- 30 degree surcharge angle: 2.100 ft^2 (0.195 m^3)

Therefore the range of the quantity of material per running foot of the conveyor is:

Cross sectional area X loose bulk density per cubic foot x foot of belt

81.2 lbs/ft 1.804 ft^2 x 45 lb/ft^3 x 1.0 ft = 81.2 lbs/ft
to
126 lbs/ft 2.100 ft^2 x 60 lb/ft^3 x 1.0 ft = 126 lbs/ft

The quantity of material conveyed at 500 fpm then ranges from:

1,218 tons/hour
81.2 lb/ft x 500 ft/min x 60 min/hr/2,000 lb/ton = 1,218 tons/hr (1,105 mt/hr)
to
1,890 tons/hr
126 lb/ft x 500 ft/min x 60 min/hr/2,000 lb/ton = 1,890 tons/hr (1,750 mt/hr)

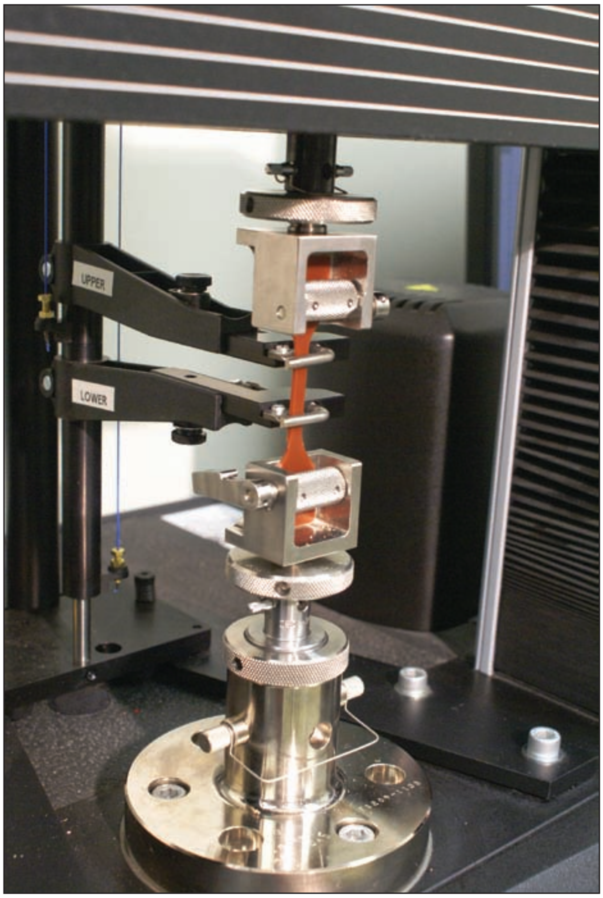
Summary of example

The differences in loose bulk density and surcharge angle yield a shortfall in conveyor capacity of more than 600 tons/hour. This error would have a major effect on the ability of the coal handling system to achieve its production rate, and therefore hinder the ability of the entire plant to achieve its operational goals. If this plant relies on 1,800 tons/hour to fill its day bins or coal bunkers and only gets 1,200 tons/hour through the system, the plant will need to operate its conveyors on a longer schedule, increasing hours for both personnel and equipment, or downrate its generating capacity.

What it all means

All coal is not one coal. One coal is not all coal.

No two bulk materials are the same, no matter what type or classification they are. This is the main reason why physical testing of a bulk solid is so important to proper design of bulk material handling systems. The cost of testing



A test of tensile strength is being performed on the machine. The test is done by stretching an "hour-glass" shaped specimen until it fails (breaks).

By running an abrasive (like sand) between a rubber disk and a sample of material, the dry abrasion tester checks three-body abrasive wear, as between a conveyor belt, a metal chute liner, and the bulk material.

is a minor part of the overall cost of a material handling or conveying system. Having this data is one of the most important tools for trouble-shooting the conveyor in the future, when processes or raw materials change.

If an existing material handling system works now, it should continue to work as long as the material stays the same and the equipment does not suffer wear or abuse that changes its performance. But changes in material – from changes in source or increased moisture from rain, or from changes in the process or in the equipment, like increasing the speed of the belts to move more material or changing a liner inside a chute – can have dramatic consequences on the performance of a coal-handling system.

And when a material handling system is being engineered, whether designed from the ground up, or substantially rebuilt, then the materials it will carry needs to be carefully tested to achieve the overall performance required and receive the maximum return on investment.

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