Fiber Focus

Winter 2011 Volume 1 No D

Brought to you by: **Material Flow Solutions, Inc.**

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Flow Properties of Fibrous Biomass Materials

Background. Many biomass energy conversion projects are initiated, but few actually make it to the final phase. The reason for this phenomenon is the lack of consideration give to the material handling end of the process. Significant effort goes into making the bio-reactor produce the right chemical or energy products. In fact, much of the research in this area today is associated with yields, kinetics, and thermal effects. While these are formidable yet essential tasks, the handling system is equally formidable, equally essential, yet often ignored. One considerable issue with using biomass as a replacement for either energy or the production of key organic raw materials is the reactor's collection and distribution system. Biomass is inherently light-weight, making the handling aspect of energy creation complicated by the sheer magnitude of the volumetric flow rate required to obtain the necessary tonnage. Biomass materials are inherently difficult to handle. Although these materials do not usually have any intrinsic cohesion caused by significant adhesion of individual particles, they do possess large strength values due to fiber interlocking, elastic wind-up effects, and the pulling of fibers from the mass during a shear event. In some cases the elastic properties of biomass materials result in very large arching dimensions (in excess of 25-feet). However, that same material – when placed in the proper bin configuration – can flow without hang-up from an outlet only a couple of feet in diameter. Extreme care must be taken when handling these very elastic materials to assure that the pseudo-cohesive problems do not cause problems in the feed system. At the heart of understanding biomass flow problems is the ability to measure and interpret flow properties relative to the handling and reaction processes. Normally we would be concerned about minimizing the critical flow properties such as unconfined yield strength to mitigate hang-up behavior in the flow system. However, reducing hang-up behavior with biomass is quite complicated. For example, both arching and rathole behavior are directly proportional to unconfined yield strength. However, these hang-up tendencies are inversely proportional to the bulk density on the material. Most granular materials are only moderately compressible and relatively heavy, so only the yield strength governs the ability of a process to handle a bulk material. However, biomass densities can change by 200% to 400% as pressure is applied to the bulk. The lose packed densities are often very light, resulting in excessively large arching and rathole dimensions, even if the unconfined yield strength values are not large. Biomass materials are inherently anisotropic. They exhibit

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In This Issue

-- IN THE NEWS --

Dr. Kerry Johanson
will present at:

Powder & Bulk Engineering, Conference & Exhibition

Atlanta - 2012

Course 203:

A Mechanistic Approach to Reducing Particle Size

Tuesday, March 13
1:00 – 4:00 pm

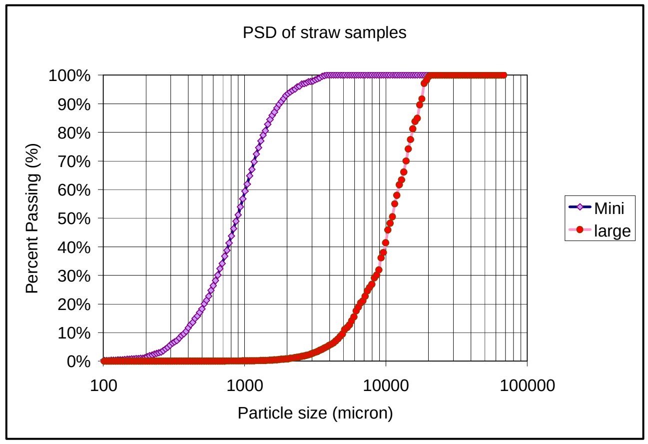
Course 501:

Strategies to Prevent Material Degradation in Process Equipment

Thursday, March 15
8:00 – 11:00 am

different properties in different directions. Consider unconfined yield strength as the resistance to shear as bulk material attempts to initially yield or flow. With biomass, the resistance to shear depends on whether the material is shearing in the direction of the grain or against the grain of the biomass. Shearing straw against the cut fibers can result in large pseudo-strength caused by the straw fibers acting like small springs and elastically deforming the mass during shear. However, inducing shear along the straw grains requires each grain to overcome only the frictional behavior of straw particles sliding past straw particles. Very little elastic deformation occurs. Using funnel flow bins to handle biomass requires shear across grains to induce flow resulting in hang-ups. However, placing the same material in a mass flow bin with sufficient velocity aligns the fibers causes shear along the length of the grain, resulting in low peusdo-strength hang-ups.

Random orientation of Biomass Particles in processing equipment. Examining a systematic review of straw flow properties, we deduce the effect of particle size and moisture content on bulk strength. Since this Newsletter does not contain sufficient space to explore all the effects on biomass strength, we will focus on strengths generated primarily due to random orientation of particles. Measuring strengths along the grain of the biomass would give different results. In the course of this study we measured both strength values, but only the cross-grain strengths are presented here. Please contact us if you wish more details on this testing capability. In the interest of brevity, we will compare the flow properties of just two straw materials. One material is cut wheat straw with a particle size about 2-inches long. The other straw was created by milling this larger straw with a cutting mill to achieve a smaller particle size. Although other straw sample sizes were measured in this study, we have chosen to present only these two sizes here. The particle size difference between these materials is an order of magnitude.



Particle Size Distribution of Two Straw Samples

Density. The density of the two straw samples was measured at various moisture contents that would be experienced during typical handling processes. Note the very light densities for the larger straw particles. There is a significant void structure within the straw particles themselves. Simply cutting the straw still maintains the integrity of the particle and results in very light densities. The density also tends to increase as the moisture content of the straw is increased. Intuitively, this makes sense due to the additional mass of the water causing heaver materials. However, when we consider the density of fine ground straw particles, we discover very different behavior. The density of the fine particles is considerably larger than the density of the large cut straw. This also makes sense since the grinding action breaks the particles, releasing the

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Fiber Focus Answers

Coming Next Quarter – Viscosity of Slurries

Biomass slurries are difficult to handle, particularly when the solids content size are so large. This is specifically due to the fibrous nature of the particles. Biomass particle fibers typically manifest significant yield stresses during shear. If biomass fibers are small, the slurry behaves as a homogenous material and traditional methods can be employed to measure the viscous behavior of the biomass slurries. However, at some particle size the material behaves more like a bulk solid with fluid surrounding the mass. In our next issue of Fiber Focus we will explore conditions when biomass slurry can be treated as a typical non-Newtonian fluid and when the material must be treated as a two-phase system with bulk solid surrounded by fluid. At Material Flow Solutions, we measure the viscosity of biomass slurries.

Future Topics

To put you at the cutting-edge

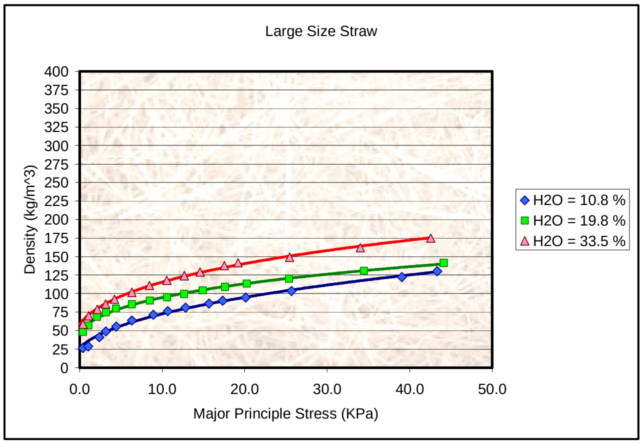
Next year in Fiber Focus we will discuss:

- Viscosity of Slurries
- Handling System Design
- Milling Biomass – in depth
- Feeding Biomass

We encourage and welcome your suggestions and special requests for biomass handling topics which you would like to see included in future editions of Fiber Focus.

Contact: Susan at 352-379-8879

void structure within the particles. The fine particles are shells of the tubular cut straw particles. They can pack more tightly together resulting in a denser straw. The density decreases with increasing moisture content. This is somewhat counter-intuitive until we realize that cohesive forces between wet particles allow a more lose packed bed and result in a lower bulk density. This cohesion allows creation of more stable, loose packed, conditions in the bulk material. However, even at the highest moisture content, the density of the finer material is between three and eight times greater than the more coarsely cut straw. This low density can have a significant effect on the tendency of biomass to arch in hoppers.

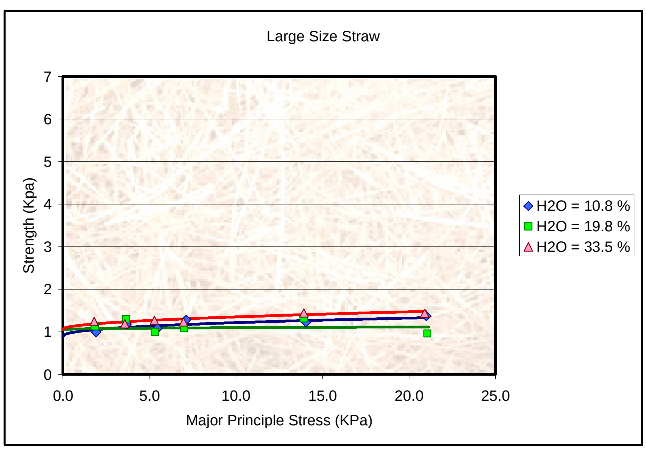


Density versus Strength of Large Size Straw

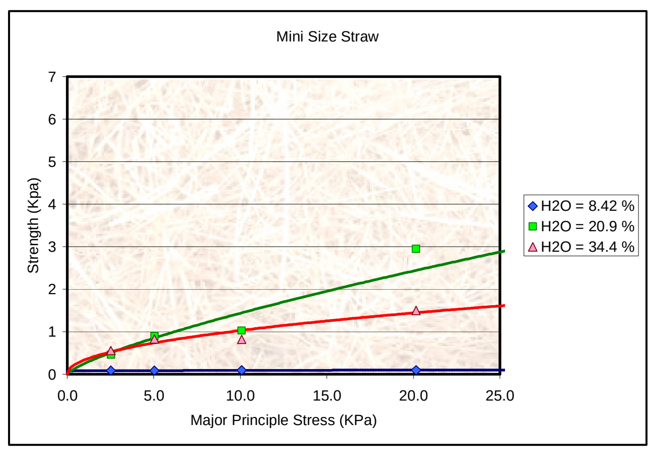
Strength. Consider the strength measurements for these two materials. The large particle size strength is nearly independent of moisture content, and is almost flat as a function of consolidation pressure. A standard analysis used by some solids flow practitioners computes a flowability number by dividing the major principles stress – say at 10 KPa – by the strength at that consolidation pressure to yield a flowability number of about 8 for this material, suggesting that this material is free flowing. This simple analysis provides faulty data when applied to biomass materials. The strength of the fine ground straw was measured and found to be a strong function of the amount of moisture in the system. There is very minimal strength at low moisture content near 8%. However, increasing the moisture content to 20% results in a maximum strength value. Further increasing the moisture content to 34% actually decreases the strength. It is important to note that the critical arching dimension for a given material is directly proportional to the strength and inversely proportional to the bulk density. The equation expresses the critical arching dimension

$$AI = \frac{fc \cdot H(\theta)}{\gamma \cdot g}$$

(*AI*) calculation mathematically, where (*fc*) is the bulk unconfined yield strength evaluated at or near the outlet of the hopper, (γ) is the bulk density of the material, $H(\theta)$ is an arching constant based on the shape of the outlet. $H(\theta)$ is about 2 in conical hoppers and about 1 in plane flow hoppers.



Unconfined Yield Strength of Large Size Straw



Unconfined Yield Strength of Mini Size Straw

Arching and Hang-up. We computed the arching and rathole dimensions for these two materials at various moisture contents. This method of analysis relates the flow properties back to behavior in the process and is the preferred method to determine real flowability. The primary interest is determining whether the bulk material will arch or form a rathole in my process. Computing the critical rathole and arching dimensions gives a good indication of potential trouble in a biomass processing system. The arching and rathole dimensions of large size straw are presented here. Because of the very low densities of the large cut straw, the small strength measured causes big arching and ratholes problems in bins and process equipment that do not allow or induce particle orientation in the direction of flow (i.e. funnel flow bins). The large size straw could arch over 7 meter outlets if

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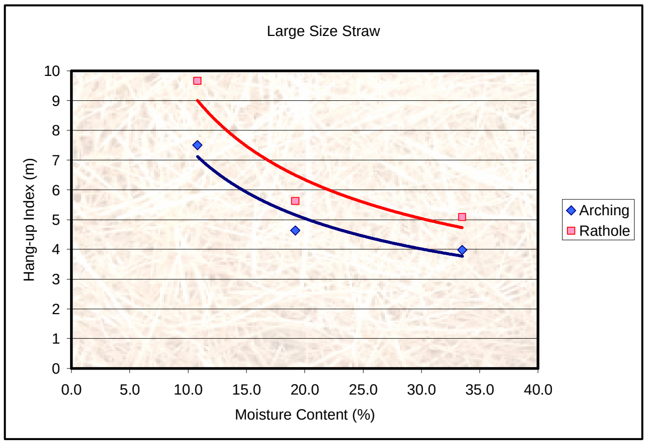
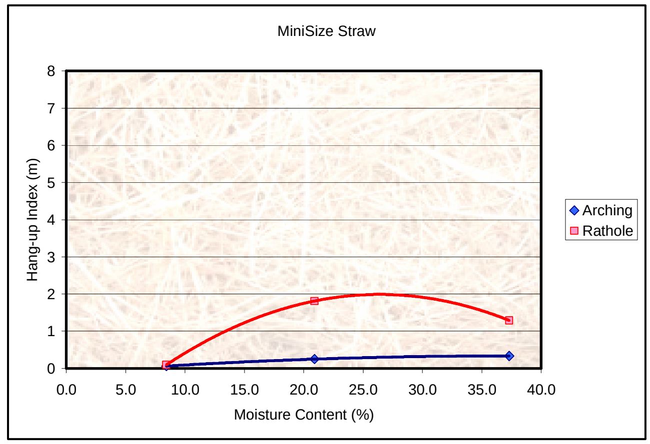
placed in funnel flow bins. However, the larger density for the finer material provides more gravity induced stresses to knock down arches. The dry material will flow easily from very small outlets (about 4-inches). Increasing the moisture content increases the arching tendency, but the maximum arching potential would produce a critical arching dimension of only 0.3 meters. This results in very reasonably sized outlets for flow. Rathole dimensions for this finer material are likewise reasonable.



Arching and Ratholing of Large Size Straw



Arching and Ratholing of Mini Size Straw

Conclusion. The moral of this story is that proper design of biomass plants starts with a good characterization of biomass flow properties. Estimating flowability of biomass using traditional methods does not apply. We strongly recommend using the arching and rathole dimensions as key parameters to determine poor or good behavior in your biomass process. One straw requires simple traditional designs to assure flow, while the other straw will require significant mechanical methods and special bin designs to assure reliable flow. We stand ready to characterize any biomass material you have and provide guidance in successful process design.

At a Glance: Milling of Biomass

http://www.p2ec.org

http://us.123rf.com

There is a movement in the biomass industry to optimize particle size of the feed stock to maximize the yield of products that may be used as key energy feed stocks or chemical building blocks. Much of the work is focused on getting the yield right. However, material handling is also very dependant on the choice of feedstock particle size. Because of the dominant role of the handling segment of biomass energy systems, the role of particle scale properties can not be ignored. Development to maintain property yields must be done in tandem with work to obtain the best flowing material. This suggests that the choice of milling and sizing operations will be a key factor in any modern biomass project.

Materials decrease in particle size for a variety of reasons. Some materials are brittle and fracture (break in half) when subjected to impact events. Some materials are insensitive to direct fracture, but chip off surface defects as the particles undergo an oblique impact and slide across the surface. Some materials are sensitive to particle breakage due to stress/strain events which crush particles at a given stress level and strain in process equipment. Some particles require significant strain to cause yield and are sensitive to cutting or tearing as close tolerance moving parts pinch the material and disrupt the particle fiber structure, creating smaller particles. A typical biomass material is subject to several of these mechanisms.

It is critical to match the particle size reduction mechanism experienced by a given biomass to the particular milling method or set of events present in the unique plant production facility. For example, if impact during processing dominates the milling process flow behavior, then particle size reduction due to impact behavior is the critical property to measure. Using a tester that causes size reduction due to stress and strain behavior may give erroneous results when applied to processes which are impact dominated. Ideally, you would use process steps that are effective in optimizing the particle breakage. If the biomass is sensitive to cutting, but not fracture, then mills

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that induce sufficient particle strain to cut or tear particles apart should be considered. In this case, an impact mill would be of little use. However, once the particles are cut or chipped, impact may be useful in further reducing the particle size of the milled product. This change in behavior is due to the fact that many biomass materials are anisotropic and exhibit different breakage behaviors with the grain and against the grain.

It stands to reason that knowledge of the type of breakage occurring with a given material, as well as the magnitude of breakage, is critical when considering the type of system to use to prepare the biomass material for eventual use in fermenters and reactors. At Material Flow Solutions, we have developed several tests that essentially isolate the different types of particle breakage mechanisms. These tests can be used to determine how sensitive a given material may be to a prescribed breakage mechanism. We can couple this data with population balance models and determine the magnitude and type of breakage occurring with each material. This information is needed to make an educated decision about using a particular mill or piece of process equipment in biomass handling facilities. These tests will help optimize mill selection or predict mill effectiveness if the mill is already in place.

Population balance models allow identification of critical particle breakage mechanisms through the computation of breakage selection coefficients. When this is coupled with a structural examination of the biomass particle, a powerful tool evolves which allows enhanced particle breakage modeling based on particle structure and breakage mechanism. More will be forthcoming about milling of biomass material in subsequent issues of this newsletter.

Learning the Trade – Flow Properties Principles

Knowing and understanding key material properties is power to characterize bulk material flow behavior. We will empower you quarterly as we discuss one of these fundamental flow properties and its industrial application.

Material Spring-back as a flow property. The spring-back flow property of fibrous biomass material is directly related to the density and elastic properties of the material. First, we will review material density. It is a function of the stress level and strain history of the material, the temperature of the bulk material, as well as moisture content and particle size. It is used in conjunction with other flow property data to determine the limiting rates of particulate materials. Spring-back is a property of elastic materials and related to the change in density as the material is placed under pressure and then relieved of the pressure forces. At Material Flow Solutions, both density and spring-back are measured using uniaxial compression of the loosely packed bulk biomass material. Spring-back is measure by placing material in a cylindrical test cell and applying a load. The density at this load is recorded and then the load is slowly removed and the density during the unloading process is measured. The operation is repeated using a series of increasing loads. Plotting the data yields a series of density spring-back curves. We can also compute the percent spring-back of a biomass material as the percent change in density relative to the maximum density obtained just prior to unloading in this procedure. A spring-back of 0% indicates that the material density after unloading is identical to the maximum density obtained at the maximum stress applied. A spring-back of 100% suggests that the density after spring-back would equal zero (please note that 100% spring-back is totally unrealizable and could not happen with real materials). Most materials have a spring-back of about 3% and any spring-back value over 12% denotes a very elastic material. Biomass materials measured at MFS possess spring-back values between 22% and 52%, indicating that great care must be taken when handling and designing for these materials. Biomass may become elastically bound in equipment due to lack of volume change at or near outlets. The arching potential for elastic biomass material in bins and hoppers is high. For this reason, flow along process vessel walls must be allowed for these very elastic materials. Failure to design process equipment for elastic relieve will result in costly hang-up issues. Measuring biomass spring-back gives design engineers and plant managers critical data to make the process work "right the first time."

Pictures compliments of: ***http://media.treehugger.com***, ***http://dnahtigal.files.wordpress.com*** and ***http://w.ukagriculture.com***