Flow Properties of Fibrous Biomass Materials

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Abstract

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.

Key words: Biomass, strength, cohesion, density

Introduction

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 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. 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.

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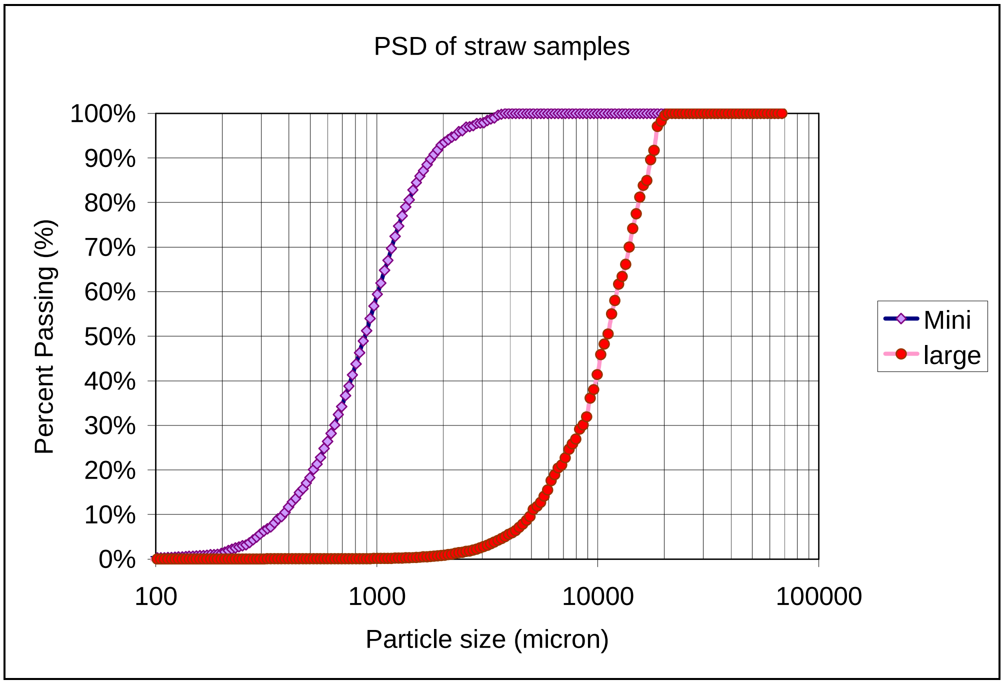

Figure 1. Particle size distribution of two straw samples

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 thevoid 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.

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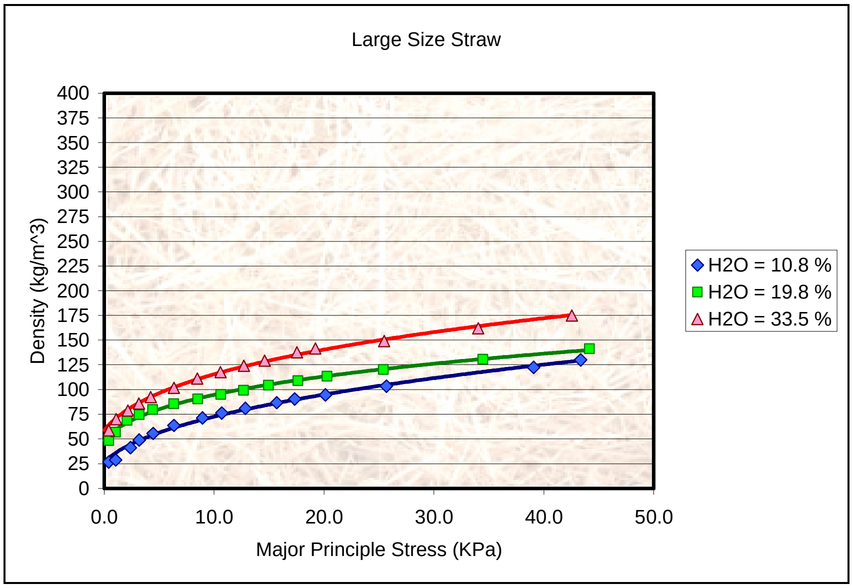

Figure 2. Density versus strength of large size straw

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*) 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.

$$AI = \frac{fc \cdot H(\theta)}{\gamma \cdot g} \qquad \text{(equation 1)}$$

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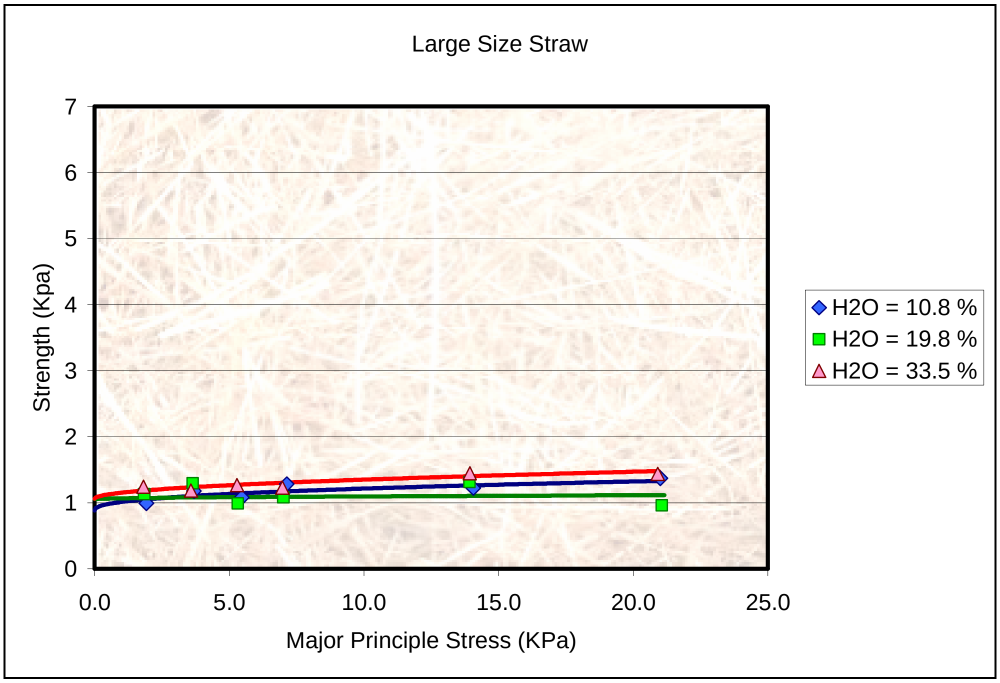

Figure 3. Unconfined yield strength of large size straw

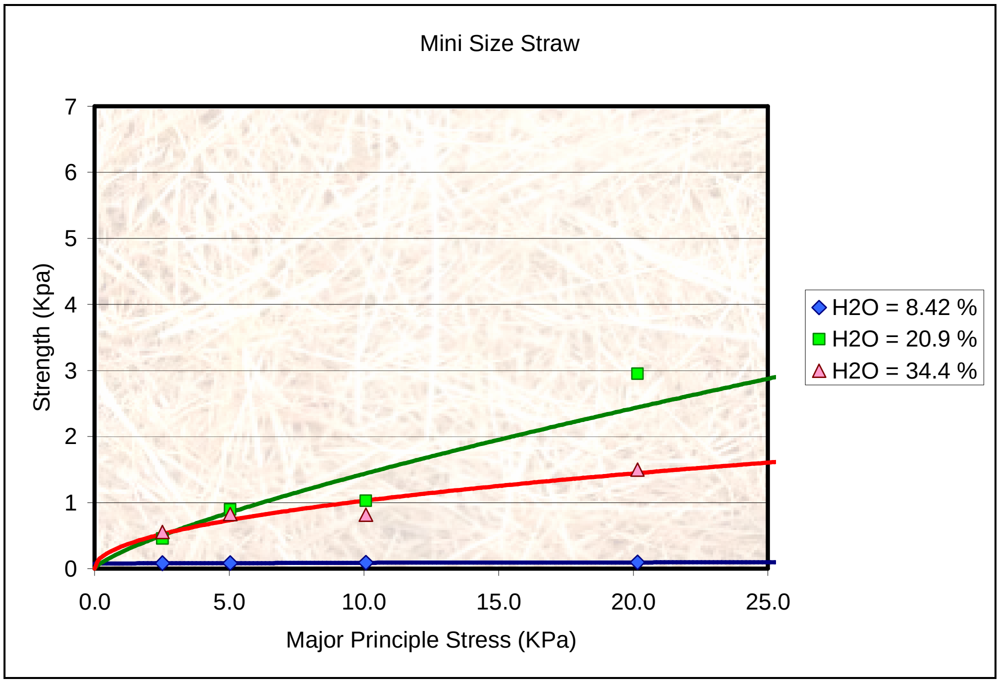

Figure 4. Unconfined yield strength of mini size straw

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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 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.

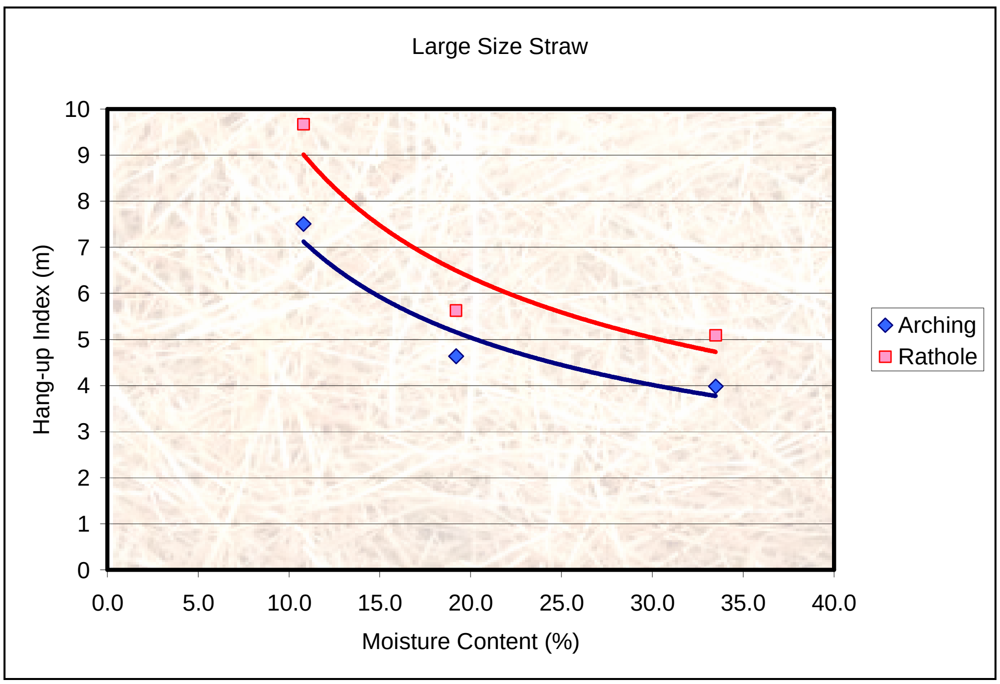

Figure 5. Arching and ratholing of large size straw

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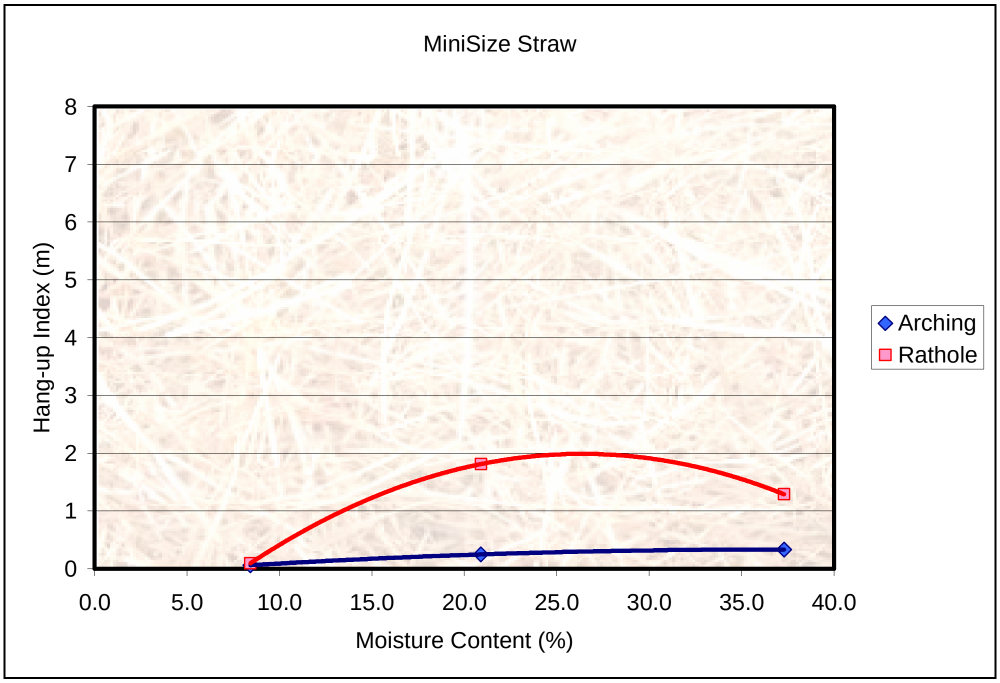

Figure 6. ***Arching and ratholing of mini size straw***

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. At Material Flow Solutions, we stand ready to characterize any biomass material you have and provide guidance in successful process design.