ABSTRACT

Ogden, Cedric A. Ph.D., Purdue University, December, 2010. Flow Mechanics of Switchgrass Bulk Solid in Hoppers under Gravity Discharge. Major Professor: Klein Ileleji.

There has been increased interest in large-scale industrial use of lignocellulosic plant biomass as an alternative biofuel replacement of fossil fuels (coal) in power plant boilers. Switchgrass (*Panicum virgatum L.),* a perennial energy crop, has been one of the favorable feedstocks considered as a dedicated energy crop in existing systems. However, the physical and flow properties of switchgrass particulates differ from coal due to its inherent low bulk density, high aspect ratio and fibrous nature. Because of the very different characteristics of switchgrass compared to most bulk solids of rigid-plastic nature, the fundamental flow mechanics differ as well. This makes it difficult or impossible to feed switchgrass into utility boilers using existing handling equipment such as hoppers designed for coal. Thorough hopper design studies for irregular-shaped particulates such as switchgrass do not exist; this provided a need to investigate fundamental material properties of switchgrass particulates and their effect on the flow mechanics in hoppers under gravity discharge.

Relationships between particle and bulk properties of switchgrass ground to geometric mean sizes (d_{wg}) of 0.98, 0.70 and 0.34 mm by hammer milling through screen sizes, 6.4, 3.2 and 1.6 mm, respectively, were evaluated. Particle size distribution decreased with size reduction indicating a smaller, more uniform particle size. Bulk density and particle density increased with size reduction indicating a less compressible bulk solid and improved handling. Particle shape (image analysis) suggested that the needle-shaped nature of switchgrass particles is an inherent characteristic that causes poor flowabilty and size reduction does not influence the shape of switchgrass particles.

Flow properties determined by shear testing provided relationships between compression and material strength. A comparison of flow properties to physical properties showed strong influences of particle size, particle size distribution and bulk density on the unconfined yield strength (UYS) and cohesion. Flow index values classified ground switchgrass of 0.98 mm d_{wg} as a cohesive poor-flowing material. Improved flow was suggested when switchgrass was ground through screen sizes smaller than 6.4 mm, that is for d_{wg} of 0.70 and 0.34 mm, respectively.

Dr. Andrew Jenike's (1964) hopper design principles were applied to the ground switchgrass material. Observed discharge openings through experimental hopper tests agreed quite well with calculated results of Jenike's method. A larger discharge opening was required for larger particle size and a less dense switchgrass bulk. Modeling of the hopper flow factor for Jenike's approach and experimental hopper testing suggested that the hopper half angle, particle-particle friction (effective angle of internal friction) and particle-wall friction (wall-friction angle) were significant factors affecting hopper design for switchgrass biomass. Comparing results of an established hopper design to actual observations allowed the hopper design to be evaluated for effects of changes induced by particle size reduction on bulk solid hopper design.

The results from this dissertation work provided a fundamental understanding of material properties that comprise the flow mechanics in hoppers as well as design. This developed understanding enables design options to be effectively assessed for modifying the process or hopper to provide reliable flow of bulk solids comprised of fibrous, irregular-shaped particulates.