Simulation and Measurement of Biomass Suspension Rheology

PI: Jennifer Sinclair Curtis, Chemical Engineering, University of Florida
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Summary: Biomass is a promising source of renewable energy. Although this form of energy production holds much potential to reduce energy dependence on petroleum-based fuel consumption, ***one key challenge in the large-scale commercialization of these systems is the physical handling of biomass suspensions.*** These suspensions span a wide spectrum of solids concentrations and particle size during the various biomass processing steps. ***Fibrous suspensions are also being used increasingly in petroleum exploration applications.*** Fibers have been used since at least the 1960's in petroleum exploration as an additive to well cement to increase its strength. Fibers increasingly are added to drilling muds to alter the rheology in an effort to improve performance of the fluid for the purpose of carrying rock cuttings from the drill bit to the surface. More recently, industry has been using fibrous suspensions to solve critical problems with regard to hydrofracturing.

In this project, a combined program of simulation and experimentation is utilized to investigate the dynamics and rheology of fibrous suspensions of biomass. In order to reliably design and optimally operate biomass processes, the rheological behavior of these complex fluids over a range of solids concentrations and particle size must be understood. On the simulation side, the discrete element method (DEM), capable of calculating stresses and effective viscosity of biomass over a wide span of moisture content (using a liquid bridging model) and particle sizes, is developed. The goal is to study the rheology of well-characterized fibrous suspensions such as fishing wire and then move onto actual biomass (wheat straw and corn stover). These materials will be fully evaluated via experimentation (angle of repose and shear cell testing) and compared with the simulation results. Successful completion of the proposed work will provide insights into the rheological behavior of fiber-filled suspensions that will aid the design and optimal operation of processes in renewable energy.

Goals and Objectives: The goal/objective of this project is to predict the flow behavior of biomass over a range of liquid content and particle aspect ratios.

Project Activities, Results and Accomplishments: Shear flows of dry, flexible fibers were numerically modeled using the Discrete Element Method (DEM) and the effects of fiber properties on the flow behavior and solid-phase stresses were explored. We have verified our DEM model by a comprehensive examination of static and dynamic behavior of particle bending, twisting, and stretching. In Figure 1, this flexible particle DEM model is illustrated via a collinear collision between two flexible particles that have their major axes perpendicular to each other. In the DEM simulations, a fiber is formed by connecting a number of spheres in a straight line using deformable and elastic bonds. The forces and moments induced by the bond deformation resist the relative normal, tangential, bending, and torsional movements between two bonded spheres. The bond or deforming stiffness determines the flexibility of the fibers and the bond damping accounts for the energy dissipation in the fibers' vibration. The simulation results show that elastically-bonded fibers have smaller effective coefficients of restitution than rigidly connected fibers. Thus, smaller solid-phase stresses are obtained for flexible fibers, particularly with bond damping, compared to rigid fibers. Frictionless fibers tend to align in the flow direction with minimal deformation as the solid volume fraction increases. However, jamming, with a corresponding sharp stress increase, large fiber deformation, and a dense contact force network, occurs for fibers with friction at high solid volume fractions. It is also found that jamming is more prevalent in dense flows with larger fiber friction coefficient, rougher surface, larger stiffness, and larger aspect ratio.

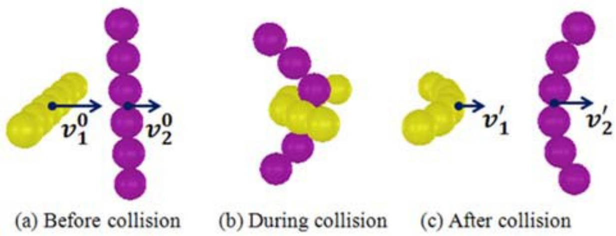


Figure 1: Snapshots of collinear collision between two flexible fibers arranged with two major axes perpendicular to each other.

We have also considered wet, flexible fibers and introduced a liquid-bridge force model for the contacts between constituent spheres. The liquid cohesive force is a function of the surface tension, contact angle, and particle radius. One example validation of the wet, flexible fiber model is an angle of repose test as shown in Figure 2 below. For fishing wire with 4% wire by volume, experiments predict an angle of repose of 20 degrees and simulations predict an angle of repose of 19 degrees.

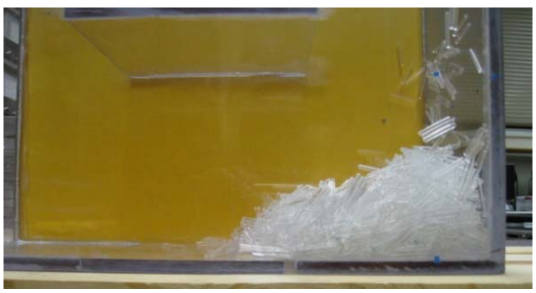
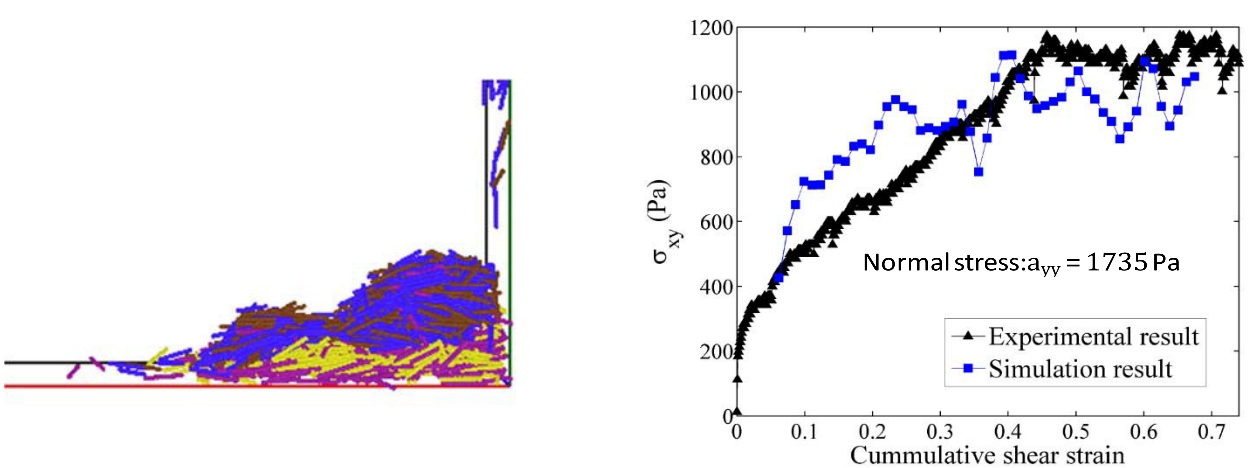
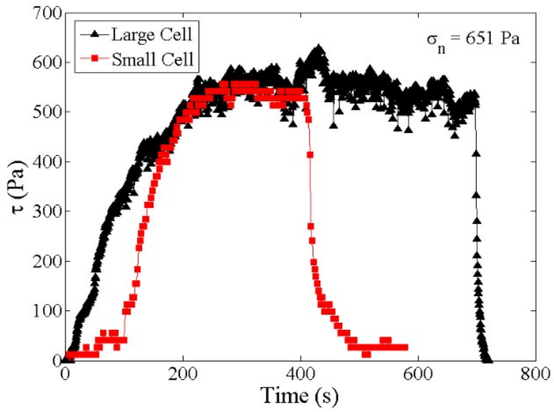


Figure 2. Experimental and simulated pile formation for wet (4% water by volume) fishing wire (2mm x 18mm)

DEM simulations also have been conducted to predict the effective stress of dry fibers and have been compared with experimental measurements in Schulze shear cell tests. We have performed these complementary experiments for the dry fishing wire in two sizes of a Schulze shear flow tester. The fibers have an aspect ratio 9, so we needed to verify that our experimental results were not system-size dependent. Figures 3a and 3b below indicates that for the fishing wire fibers the experimental results are not system-size dependent. Figure 3c shows that the simulated stress compares very favorably with the measured stress.





		Small Schultz Shear Cell	Large Schultz Shear Cell
Ring Diameters	Inner	10 cm	21.8 cm
	Outer	20 cm	36 cm
Depth of Inner Cell		4 cm	7.4 cm

Figure 3 (a), (b), (c)

Concluding Remarks: In the next reporting period, we will validate our DEM model with shear cell experimentation for wet fibers and angle of repose testing on biomass material (wheat straw).

Publications:

Y. Guo, C. Wassgren, B. Hancock, W. Ketterhagen, and J. Curtis,, "Computational study of granular shear flows of dry, flexible fibers using the discrete element method", Revisions submitted to *Journal of Fluid Mechanics*, 2015.

Y. Guo and J. Curtis, "Discrete Element Method Simulations for Complex Granular Flows" (Invited), *Annual Review of Fluid Mechanics*, **47**, 21-46 (2015)

Presentations: Plenary Talk, "The Role of Shape in Particle Transport Processes", Conveying and Handling of Particulate Solids (CHOPS 2015), Tel Aviv, Israel, May 5, 2015