ABSTRACT

Controllable continuous feeding of biomass feedstock in a biorefinery is critical to upscaling current ethanol conversion techniques to a commercial scale. Mechanical pretreatment of biomass feedstock performed using a compression feed screw (CFS) improves the ethanol yield but is subject to flowability issues, especially the plugging of biomass. The mechanical behavior, and hence, the flowability of biomass feedstock, is strongly affected by several factors, including preparation method, moisture content, physical composition, and particle size distribution. In addition, the current design of CFS is guided by limited experimentation and even fewer theoretical correlations. This thesis aims at developing computational methods to model the flow of densified feedstock in a CFS and experimental techniques to characterize the mechanical properties required for the model. We adopted a modified Drucker-Prager Cap constitutive (mDPC) law for milled corn stover (a widely used feedstock for bioethanol production) to model the material's rate-independent bulk behavior in a CFS. The mDPC elastoplastic law captures the frictional shear and permanent volumetric changes in corn stover using a continuous porosity-dependent yield surface. The parameters of the mDPC model are calibrated using a unified set of single-ended die compaction and multiple shear failure tests. In addition, we quantified the changes in the mDPC parameters with moisture content up to the water-holding capacity of corn stover particles. A Coupled Eulerian-Lagrangian Finite Element Method model developed for the CFS geometry predicts the deformation of the material using the calibrated mDPC parameters. We model the interaction between the material and the CFS surface using a Coulomb wall friction coefficient calibrated using the Janssen-Walker method for a punch and die system. A laboratory-scale compression feed screw is designed and fabricated to characterize the flow of dense granular materials in collaboration with undergraduate students in the School of Mechanical Engineering. FEM model predictions of feeding torque and mass flow rate are validated against the laboratory-scale feeder for microcrystalline cellulose Avicel PH-200 and milled corn stover. The model predictions agree with the experiments for Avicel PH-200 but have a higher error in the case of corn stover. Some physical effects, such as shear hardening and particle erosion observed in milled corn stover, are not captured using the current

implementation of the mDPC model, which explains the different model accuracies for both materials. The continuum model is used to uncover material density distribution, torque, and pressure inside the CFS, otherwise challenging through experiments. The FEM model showed a significantly higher sensitivity of the feeder performance to two material properties, namely the hydrostatic yield stress and the wall friction coefficient. The characterized variation of material properties with moisture content and the effect of each material property on the feeder performance provide strategies to engineer the feedstock for better flowability. Further, the continuum model offers a method to study design changes before manufacturing the equipment. Finally, we propose the possibility of a reduced-order analytical model based on the critical material properties and the material deformation mechanism demonstrated by the FEM model.