ABSTRACT

Hopper systems of different shapes and sizes are widely used in bulk solids industries to store and further process the particulate material. Poor hopper design causes variety of problems and results in wastage of resources. This dissertation investigates the applicability of finite element method (FEM) based continuum modeling in predicting flow characteristics of particulate materials discharging through hopper system. Throughout the years, FEM has been implemented to simulate the shear failure of particulate materials such as sand, glass beads, and pharmaceutical powders. The FEM framework is based on the underlying constitutive model. Different constitutive models are available in the literature to govern the behavior of particulate materials. These models differ in their complexity, ease of implementation, and have specific strengths and limitations. This work thoroughly investigates the elasto-plastic constitutive models available in the commercial software Abaqus in the context of hopper flow of particulate materials.

The thesis consists of three major parts, first part deals with FEM modeling of cohesionless particulate materials and corresponding verification of the hopper flow characteristics through comparison to analytical theories and empirical correlations. The second part presents quantitative comparison of FEM predicted flow characteristics to experimental results for Ottawa sand discharging through concentric and eccentric bins. Particle image velocimetry (PIV) experiments are conducted on a laboratory-scale bin to quantify different flow characteristics. The last part deals with cohesive particulate materials and presents a novel FEM approach for predicting the critical hopper outlet opening to ensure uninterrupted discharge of the stored material.

This thesis concludes that the FEM modeling based on simple elasto-plastic constitutive model proves useful in predicting different hopper flow characteristics of particulate materials. The accuracy of FEM modeling depends on detailed material characterization and corresponding implementation in Abaqus. Some modifications need to be made in the elasto-plastic constitutive models to accurately represent the bulk material behavior. The ideas presented in this thesis can be applied to FEM modeling of other processing equipment such as the rotating drum, screw-feeder, rotating blender/mixer etc.