

Chemical Engineering Dissertation Defense

Determining the role of particle interactions in flowability and trapping strategies

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Abstract

Particulate and granular materials are found in countless aspects of daily life, from the medicine we take, to the cheese dust on a snack. They play a vital role, particularly for applications involving bulk powder flow and particle-surface interactions. Despite their widespread use, predicting and controlling the behavior of particulate materials remains challenging due to their complex nature. Variations in particle properties, environmental conditions, and processing parameters contribute to difficulties in understanding particle interactions. This often leads to reduced efficiency, lower product quality, potential equipment damage, and hinders design.

This dissertation explores two routes towards quantifying and predicting the behavior of particulate materials: one focused on the industrial challenge of bulk powder flow and the other on passive particle trapping for bio-inspired material design. The flow characterization of wet powders is critical to predict performance of processes like wet granulation. The flow properties of materials were characterized using an FT4 Powder Rheometer and linked to particle properties, revealing a critical moisture content. The critical point was connected to material saturation, and the minimum liquid content for granule product in high-shear wet granulation, where the formation of liquid bridges leads to increased interparticle cohesion. To generalize these findings, a machine learning approach was utilized to identify the most influential particle properties governing the rheology of three saturated powders. A predictive framework was developed that links physical material properties directly to flow behavior.

Beyond industrial applications, particle-surface interactions are important to biologically evolved processes. The second part of this dissertation develops a quantitative methodology for the particle trapping of bio-inspired hair-like materials. An adapted centrifuge-based method was developed to measure the particle retention efficiency of hair structures on the bee's legs. Specific unbranched hair morphologies were identified as most effective for retention-based particle trapping via two mechanisms: particle-structure contact forces and mechanical retention. These findings establish a structure-function relationship, providing metrics and principles for engineering new hair-like materials. Overall, this dissertation contributes to the understanding of complex particle systems by providing new insights into powder rheology with predictive models, along with a data-driven approach for designing novel hair-like materials for particle trapping.

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