

Development of Novel Methods for Performance Assessment and Control of Hydrocyclones

Abstract

Hydrocyclones are indispensable in mineral processing for classification and solid-liquid separation tasks, yet persistent challenges exist in their quantitative assessment and operational control. This doctoral thesis addresses these challenges by developing methodologies and advancing understanding across three critical aspects: online discharge state monitoring, modeling and prediction of partition curves, and rigorous analysis of refractive index effects on particle size measurement and partition curve interpretation.

A key advancement is the development of a non-intrusive online monitoring system for discharge state detection. Utilizing tri-axial vibrometry combined with a one-dimensional convolutional neural network (1D-CNN) framework, the system classifies spray, transition, and rope discharge states with over 94% accuracy. An objective definition of the transition state for accurate data labelling was formulated through quantitative spray angle analysis. Further investigations revealed that the feed concentration needed to restore spray discharge once roping has fully commenced can be significantly lower than the level at which roping initiates. This previously unreported behavior, termed Roping Hysteresis, has major implications for process control and thickening performance.

Another crucial element is a unified parametric model for hydrocyclone partition curves, designed not only to accurately represent complex features like fish-hook and fat-tailed behaviors in a single, continuous expression, but also to serve as the structural output for predictive modeling. This model incorporates a robust definition of separation characteristics, using a novel cut-size parameter valid across diverse operational scenarios. Complementing this, a design characterization methodology based on water-only operational features was developed to capture essential geometric attributes in a minimal parameter space. These parameters—stable water split and flowrate coefficient—function as inputs for a machine learning framework employing Extreme Gradient Boosting to predict the model coefficients, enabling precise prediction of entire partition curves for varying cyclone designs and operating conditions.

Finally, the thesis investigates the influence of refractive index specification on laser diffraction-based particle sizing, addressing ongoing debates on the origin of the fish-hook phenomenon. Experimental results established that variations in the particle's specified complex refractive index affect size distribution measurements; however, the fish-hook behavior persists for hydrocyclone partition curves independent of refractive index selections, while being absent for wet sieving partition curves. This confirms it as an intrinsic feature of hydrocyclone separation, not a measurement artifact. Towards enabling accurate refractive index estimation of microparticles, a novel single-shot laser holography technique for micron-sized transmitting spheres was developed and validated, offering significant precision.

Keywords: Hydrocyclone; Partition curve modelling; Roping Prediction; Fish-Hook origin; Refractive Index estimation