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A rigorous breakage matrix methodology for characterization of multi-particle interactions in dense-phase particle breakage

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ABSTRACT

Broadbent and Calcott's breakage matrix methodology has been used for more than 50 years to model various comminution processes and to determine breakage functions from experimental data. The methodology assumes first-order law of breakage and neglects mechanical multi-particle interactions that are especially prevalent in dense-phase comminution processes and breakage tests. Although several researchers severely criticized this aspect of the methodology, Baxter et al. (2004, *Powder Technol.* 143–144:174–178) were the first to modify the methodology toward determining the elements of a feed-dependent breakage matrix. However, no non-linear breakage matrix has ever been constructed from experimental data using the modified approach. In this study, a critical analysis of this modified approach has been performed, and the non-linear breakage matrix was fundamentally derived from a non-linear population balance model. Different approaches were proposed to identify the breakage functions based on the nature of available breakage tests on multiple mono-dispersed feed samples and at least one poly-dispersed sample. Using the derived equations, available experimental data on the breakage of a binary mixture of coarse and fine limestone particles in uniaxial compression test were fitted to quantify the multi-particle interactions. Superior fitting capability of rational approximation to the effectiveness factor was demonstrated.

Keywords: Particle breakage; Breakage matrix methodology; Multi-particle interactions; Population balance; Parameter estimation; Rational approximation

1. Introduction

Comminution processes are widely used in the processing of minerals, ceramics, composites, foods, paints and inks, pharmaceuticals, etc. (Prasher, 1987). Industrial comminution processes are energy-intensive, poorly efficient, and costly, thus entailing a quantitative analysis to process design and optimization besides experimentation. Without being too exhaustive, a categorization of the major approaches for modeling particle breakage in comminution processes may be made as follows:

- purely data-driven models (e.g., Celep et al., 2011; Pradeep and Pitchumani, 2011) and empirical models such as characteristic particle size-milling time correlations (e.g., Bilgili et al., 2008; Strazisar and Runovc, 1996; Varinot et al., 1999) and particle size-specific energy correlations (e.g., Austin, 1973; Bilgili et al., 2001; Nomura and Tanaka, 2011)
- particle-scale mechanistic models, which explicitly incorporate some material properties to explain particle breakage (e.g., Gahn and Mersmann, 1999a,b; Ghadiri and Zhang, 2002; Vogel and Peukert, 2003)
- mechanistic models such as the Discrete Element Method (DEM), Finite Element Method (FEM), or their combination, which account for particle deformation, multi-particle mechanical interactions, and/or collision frequency/energy at the particle ensemble or agglomerate scale (e.g., Ahmadian et al., 2011; Antony and Ghadiri, 2001; Bagherzadeh et al., 2011; Rajamani et al., 2000; Thornton and Liu, 2004; Tsoungui et al., 1999)

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