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Sampling of cohesive bulk materials by falling stream cutters

P.W. Cleary*, G.K. Robinson

CSIRO Mathematical and Information Sciences, Private Bag 33, South Clayton 3169, Victoria, Australia

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ABSTRACT

DEM has proved to be a useful method for analysing sample bias for falling stream cutters. It provides detailed information on bias and size-dependant extraction ratios based on closely matched reference and actual samples taken from the same simulations. It has allowed the identification of operational and design parameters which influence sample cutter performance and bias. To date, only cohesionless bulk materials have been considered. Wet bulk materials typically become sticky and this strongly influences their flow behaviour and particularly the mobility of fine particles and the overall flowability of the material. The inclusion of cohesion in DEM simulation of flow from a head pulley shows that the falling stream breaks up into large fragments that move as rigid bodies. The size of these fragments depends on the degree of cohesion. The effect of cohesion on sampler performance is explored. No statistically significant bias was observed with increasing cohesion level even though the extraction ratio was observed to decline. The effect of cohesion for different aperture sizes of the cutter was also investigated. As the cutter becomes narrower the extraction ratio declines sharply. However, even for a cutter of aperture twice the particle top size (which would be highly biased for a cohesionless material) no bias was detectable. For cohesive materials the extraction ratio no longer correlates with sample bias. Cohesion improves sample cutter performance by restricting the ability of different size fractions to move independently in the congested flow region that forms at the cutter opening.

1. Introduction

The determination of the physical and chemical properties of bulk particulate materials such as iron ore, coal, sugar, alumina, wood chips and other mineral ores is important for both commercial reasons and for controlling the processes that use these as feed materials. The first step in such measurement is the taking of a primary sample of the bulk material. Such samples need to be unbiased so that decisions made using this information are well informed. Cross-stream cutters are the most commonly used and best performing type of sampler used for large-scale commercially sensitive sampling. These samplers consist of a rectangular volume with a front opening bounded by a pair of straight parallel cutter blades. They are moved at constant speed through falling streams of bulk material. Typically such sampling is performed once a stream has separated from the head pulley of a conveyor belt. Some of these falling particles flow between the cutter blades and are captured to form a primary sample. This material is typically crushed, sub-sampled, milled and sub-sampled again until the volume is small enough to perform the desired laboratory characterisation tests for composition and/or properties.

The generally accepted rules for the design of falling stream cutters, as discussed by Gy (1982, 1992) and Pitard (2005), are that the cutter aperture, A, should be at least three times the maximum particle size, D, and that the cutter speed should not exceed $0.3[1+A/(3D)]$ m/s. These are based predominantly on practical experience with commercial operations and on small scale laboratory experiments performed by Gy and Marin (1978).

The testing of samplers to establish the presence or absence of bias is an expensive and difficult task. It normally involves stop belt tests where the conveyors are stopped (leading to production loss) while large sections of material are physically removed from the belt for sub-sampling. Large numbers of replicate tests (10–100) are normally required to detect small sample biases because of the many other larger sources of variability. Over the last decade another more cost effective and statistically more repeatable approach using computational sampling has been developed. The underlying numerical method is the Discrete Element Method (DEM), which simulates particulate systems at the particle scale by following the trajectories and collisions of all particles and boundary objects in the system. Robinson and Cleary (1999) introduced two-dimensional DEM to the analysis of cross-stream cutters with bias assessed relative to a predicted reference sample. This was extended to three dimensions in Cleary et al. (2005). Later, Cleary and Robinson (2008) introduced close matching of the specific particles in the reference and actual

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* Corresponding author.
E-mail address: Paul.Cleary@csiro.au (P.W. Cleary).

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sample. This eliminates much of the natural variability in the feed size and composition distributions along the conveyor belt and allows very small biases to be detected with quite small numbers of replications. This work showed that sampler operating conditions existed, that while outside the current design standards for samplers, produced more accurate samples than variants that do meet current standards.

In computational sampling we can eliminate all variability or errors in sampling caused by the physical and reference samples being taken at different positions in a variable stream of material. However, by using a model we also introduce a model error which relates to how well the computational material represents the real material in the physical system. So we can sharply reduce one source of error but at the cost of introducing a new one. Neither physical nor computational bias tests are absolutely accurate and depending on which error is largest, either approach may be more accurate for a specific installation. Over time, the computational models will continue to become more realistic with increasingly accurate material characterisation. This means that model error variance will tend to become smaller than reference sample error variance. This and the overwhelming cost advantage mean that over time there is likely to be a transition from plant to computational testing.

The specific implementation of the DEM method used here has been validated against experiments for several applications. Cleary and Hoyer (2000) and Cleary et al. (2003) used high speed photographs to validate DEM predictions of charge distributions in laboratory scale Centrifugal and SAG mills. Cleary and Hoyer (2000) also obtained close agreement between DEM and measured power draws for the Centrifugal mills. McBride and Cleary (2009) compared DEM predictions of mass flow rates in a Olds elevator (type of screw conveyor) to experimental values and found extremely close agreement across a broad range of operating speeds. Finally, Owen et al. (2009) have shown good agreement between DEM and experiment for the quasi-static collapse of a granular material. These validation case studies provide general confidence that the DEM method and particularly this implementation of the DEM method are generally able to provide good representations of particle flows in industrial equipment. This indicates that the general model risk associated with the use of a DEM model for computational sampling should at worst be described as "moderate". The principal model risk relates to the closeness of the representation of the material to be sampled, which depends on its size and shape distributions, the interparticle friction, and any cohesion.

Cleary et al. (2008) examined the effect of particle shape and non-traditional operating/design parameters on sample accuracy. They showed that the performance of the sampler was determined by the balance of the forces pushing material into the sampler against those resisting. Specifically, sampler performance was controlled by a congested region of flow at the opening of the sampler where material is slowed by collisional interactions with either the sampler or other particles already slowed by the sampler. The force balance in this region determines the degree to which particles are able to push through the congestion to be sampled or are deflected sideways leading to poor extraction ratios and often to bias. The main factor increasing the ability of the particle stream to push through into the cutter is its speed, which controls the momentum and energy available to overcome the resistance from the congestion. The main factors influencing the resistance to flow in the congested region are the cutter aperture and the shape of the particles in the falling stream. These factors all interact, so sampler performance is determined by a complex combination of these factors. Of the factors that were found to be important, the only one traditionally considered to be important is the aperture of the cutter. Whilst this appears to be the most important single factor, it is not the only factor that needs to be considered in sample cutter design. The recognition that force balance at the cutter opening controls sampling performance allowed identification of three non-traditional factors (cutter distance below the top of the head pulley, load on the belt and particle shape) that also influence sampler performance. The traditional inclusion of cutter speed in the rules for design of unbiased samplers was found to be unjustified. Particle shape was also found to affect the resistance of the particles to flowing into the cutter, but had a weaker that the other new factors.

More recently, Cleary and Robinson (2011) applied this same computational sampling methodology to examine the performance of laboratory scale Vezin samplers. Sensitivity of sampler performance to a broad range of material properties, operating conditions and cutter designs were considered. In all cases, the Vezin sampler was found to perform very well and demonstrated no observable sample bias.

Many particulate materials which need to be sampled can be regarded as cohesionless. However cohesive forces between particles can be very important for damp or wet bulk materials such as in-process and waste streams from mineral processing plants, naturally or purposely wetted bulk materials with significant fines fractions (such as coal and iron ore) and materials with sticky interstitial material such as clay. Such materials are sometimes described as "sticky". To date all sampler investigations reported, either experimental or simulation based, have dealt with dry cohesionless particles. Since cohesion makes material sticky and reduces its ability to flow, it will affect the resistance to flow into the sampler in the congested region at its opening and therefore the force balance that controls the flow into the sampler, Furthermore, this stickiness reduces the mobility of fine particles more than it affects the mobility of large particles. So on these bases, one might reasonably anticipate that cohesion could therefore influence the predisposition of the sampler to take biased samples. We therefore use the DEM based computational sampling method with a suitable cohesion model to explore the effect of cohesion on the flow of bulk materials through a falling stream sampling system and on sample bias and the extraction ratio.

2. Simulation configuration

The simulations were set up as illustrated in Fig. 1 using conditions which were the same as those previously modelled by Cleary et al. (2005), Cleary and Robinson (2008) and Cleary et al. (2008)

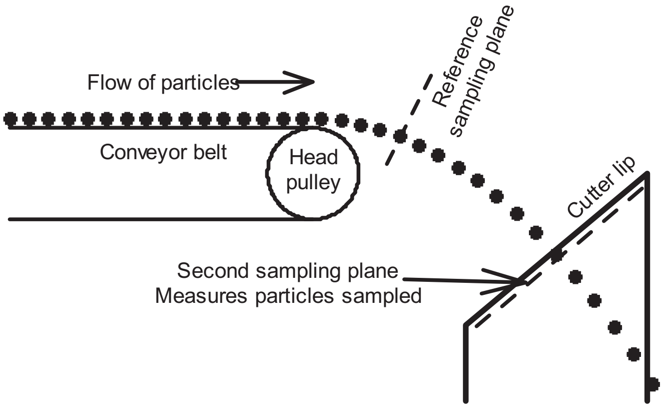

Fig. 1. Typical setup of falling-stream sample cutter. The particle stream is represented by the series of dots leading from the top of the conveyor belt, over the head pulley (the circle at the end of the conveyor) and down to the sampler in the lower right. The sample plane that performs the particle classification is shown by the dashed line that intersects the particle stream just after the head pulley.