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Spatial distributions of media kinetic energy as measured by positron emission particle tracking in a vertically stirred media mill

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ABSTRACT

The stirred media mill is a piece of process equipment used in comminution, which uses grinding media, beads of ceramic or similar material, to mediate energy transfer between a rotating impeller and a slurry of the particles to be ground. Motion of the media is vital to the action of the mill, but is often assumed to be simple in modelling due to incomplete knowledge in detail.

The movement of a media particle in a stirred media mill has been observed using Positron Emission Particle Tracking. The occupancy and the kinetic energy of the particle within the mill have been calculated and plotted in order to examine the effect of tip speed on the particle. The particle path has been shown to be different below, at, and above the impellers indicating the media are subject to different forces in the region of the impellers. Changes in velocity of the particle correspond with changes of height of the particle in the mill, caused by the particle colliding with the impellers.

The impeller speed was found to significantly affect media KE distribution in the mill. At higher tip speeds the media particle has lower energy outside the impeller zone compared to in the impeller zone indicating that there is significantly less energy transfer between the zones when the tip speed is increased. Additionally, at high tip speeds the occupancy is low in the high kinetic energy region at the impellers.

1. Introduction

Positron Emission Particle Tracking (PEPT) is a technique used to follow particles in processes (Parker and Fan, 2008; Bakalis et al., 2004, 2006; Fangary et al., 2000), giving fluid dynamic information which can be unobtainable by other means. The use of PEPT to visualise media motion in the laboratory scale stirred media mill is established (van der Westhuizen et al., 2011; Barley et al., 2004).

PEPT provides an empirical alternative to DEM and CFD computer models (Liu and Barigou, 2013; Boucher et al., 2015) and has been pursued in this work because it provides similar information based on real data. PEPT data could be used to validate these types of models.

The vertically stirred media mill is used in comminution, particularly in the fine grinding of minerals for which it can have efficiency benefits over the tumbling mill (Radziszewski and Allen, 2014). The stirred media mill employs grinding media such as ceramic beads driven by a rotating impeller.

The energy used in comminution is transferred via the media beads. It is widely considered (Kwade et al., 1996; Kwade, 2004; Jankovic, 2001; Eskin et al., 2005; Varinot et al., 1997, 1999; Stamboliadis, 2007) that particle size reduction occurs during collisions between media (stress events) in which the particle is trapped between media beads and energy is transferred from media to particles. The distribution of media kinetic energy within the mill is thus of interest in quantification of the process and can be ascertained using PEPT.

2. Materials and methods

2.1. Milling

The majority of data shown in the paper was generated using Imerys' laboratory scale mill, a 500 W Cheetah sandgrinder. The mill has a 4 pin impeller housed in a cylindrical pot of 150 mm diameter. The impeller arms are pins of 135 mm in span and 25 mm in diameter.

A slurry of calcium carbonate of a passing size 60% below 2 μm and Kraft bleached softwood pulp dispersed in water was processed.

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Grinding media of diameter 3 mm were used, which were made from 3 different materials varying in density – mullite (SG = 2.7), alumina (SG = 3.8) and zirconia (SG = 5.6).

Impeller tip speeds of 1.77, 3.53, 5.30, 7.07 and 8.48 ms^{-1} were used, corresponding to 250, 500, 750, 1000 and 8.48 ms^{-1} respectively. This range represents the full operating range of this piece of equipment.

50% media volume concentration was used in all the experiments.

2.2. Data processing

Data processing was based on previous work done using PEPT in the imaging of milling at the University of Birmingham (Barley et al., 2004; Barigou, 2004; Nuclear Physics Research Group, 2014), however there were some slight changes to the procedure which were made based on the initial results from the occupancy and kinetic energy diagrams, which were of higher resolution than others had previously published.

The processing steps taken in this work were:

- The raw data was run through Track, the software developed by the School of Physics at University of Birmingham for initial interpretation of the raw PEPT data. Some optimisation of the camera was required prior to this step according to the standard equipment procedure. The output from this step was a list of positions in Cartesian coordinates at which the particle was observed, with corresponding times.
- For the plots in Section 3.5, the data were converted into cylindrical coordinates as these were considered to represent the particles roughly circular path around the mill better than Cartesian coordinates. In Section 3.1, the locations are recorded in Cartesian coordinates. In both systems, the origin is assumed to be the bottom and centre of the mill chamber. This is calculated from the lowest point at which the bead was recorded, and the mean values of x and y, with the dimensions independent.

$$z_0 = min(z), x_0 = \bar{x}, y_0 = \bar{y}$$

- Calculations were performed of the particle's velocity and kinetic energy at each point. To do this the time and distance between two consecutive observed locations was used to give the particle's instantaneous velocity (referred to as simply 'velocity' from now on). Two consecutive measurements of these velocities, and the mid points of the times the velocity was observed, were used to determine the particle's instantaneous kinetic energy (referred to as simply 'kinetic energy' or 'KE' from now on) using Newton's Law, Eq. (1),

$$KE = \frac{1}{2} m v^2 \tag{1}$$

  where m is calculated from the media density and its given diameter of 3 mm.
- Occupancy and kinetic energy diagrams were made using cells of equal volume, azimuthally averaged to make a 2-dimensional plot of the entire contents of the mill.
  In the occupancy and kinetic energy diagrams, the left of the diagrams represents the middle of the pot and the right the outside, with the media locations averaged around the circumference as in Fig. 1. The cells are broader nearer the impeller so as to be all be of equal volume. The plots are in two parts, with the left-hand picture showing occupancy i.e. what proportion of time the tracked bead spent in that cell – brighter areas are where the media spent more time, and the right-hand picture indicating kinetic energy of the media at each location, averaged over all the events at which the tracked bead was recorded in that cell. Superimposed on the KE plots are arrows showing the axial and radial components of velocity with the radial component ignored. These plots allow the best visualisation of media flow patterns as the radial component of velocity is dominant in determining the KE. It is assumed that the tracked bead is representative, in the sense that measuring the locations of one bead over a long time is equivalent to taking a snapshot of all the beads' locations at one instant, after normalisation.
- The variables given by data processing were used to generate graphs and figures, along with process and product data.

Positional data are shown as recorded. Filtering of the data was considered, however the potential for excessive smoothing of the data was thought to outweigh the possible benefit in noise reduction, in the absence of other means of quantification of the bead's path.

Runs were performed up to a consistent energy input of 30 Wh. The length in time of the runs was shorter for higher tip speeds, however in all cases the time was considered sufficient for the bead to access all parts of the mill a representative number of times.

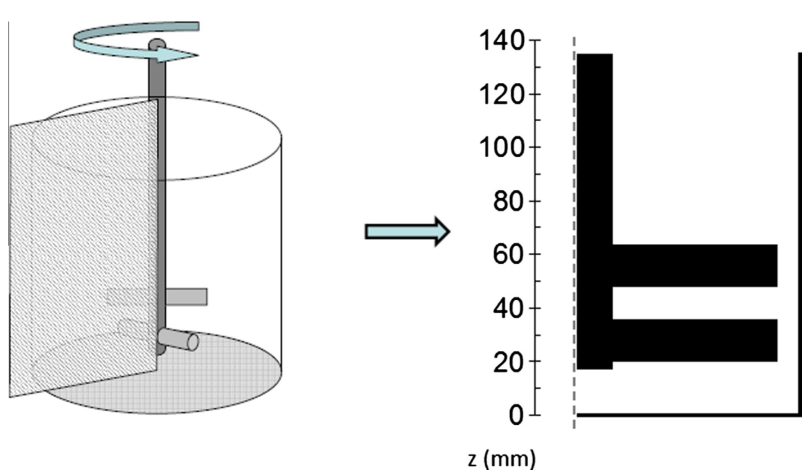

Fig. 1. Diagram of how 2-D plots are generated by azimuthal averaging.