Positron emission particle tracking inside a laboratory batch jig

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Synopsis

Owing to decreasing high-grade ore reserves, there is a need for better understanding of the jigging process to improve the recovery efficiency of finer, lower grade material. The use of positron emission particle tracking (PEPT) was examined as a technique to study the motion of iron ore particles inside a laboratory batch jig. PEPT is a non-invasive method that can provide three-dimensional kinetic data on a particle in laboratory-scale processing units and has been successfully used to study mills, hydrocyclones, and flotation. Experiments were conducted to determine whether PEPT would be a viable technique to study iron ore jigging and what valuable information could be obtained. The results indicated that detailed information on the stratification rate of a particle could be obtained, with adequate resolution to track the particle's movement through an individual jig pulse.

Keywords

positron emission particle tracking, PEPT, jigging, gravity separation, modelling.

Introduction

Stratification through the depth of a jig bed is a result of the differential settling of particles under the influence of gravity. The main parameters that influence the stratification behaviour are the pulse cycle and feed properties (Mukherjee and Mishra, 2006). There have been many attempts to predict the performance of jigs over the years, but due to the complex interactions between the different parameters most of these models and theories provide only insight into the jigging process rather than predictive results.

Most of the theories are verified using empirical data based on the feed and product of the jig and not on the movement of the material inside the jigging chamber. This, however, is not sufficient to fully understand the jigging process and a deeper study of the movement of the particles inside a jig is required. Tracking of individual particles in a jig is therefore important. Only two experimental techniques have been used in the past: optical high-speed camera (Kuang *et al.*, 2004) and positron emission particle tracking (PEPT) (Williams *et al.*, 1998). The disadvantage of the optical techniques is that an artificial transparent sample is used, while with PEPT almost any type of jig feed can be used. PEPT shows significant promise as a research tool in the mineral processing industry. Using a radioactive tracer, PEPT allows for the tracking of a single particle inside a closed system without interfering with the process. PEPT has been successfully used for describing mineral processing systems such as mills (Bbosa *et al.*, 2010), hydrocyclones (Chang *et al.*, 2011), and flotation cells (Waters *et al.*, 2008), and the technique is gaining momentum as a research option.

PEPT makes use of a radio-isotope tracer that decays through the beta-plus mechanism and emits a positron, the positive counterpart of an electron. When an electron collides with a positron, it is annihilated, releasing two back-to-back 511 keV γ-rays, 180° apart within ±0.3° (Parker and McNeil, 1995). When a particle that emits these gamma rays is placed inside a cylindrical array of detectors, its position can be determined by extrapolating lines from the points where the gamma rays are detected and then finding the positions where these line cross (Figure 1).

PEPT monitors the behaviour of a single particle inside a jig. Real-life scenarios can be emulated and the movement of tracers with different shape, size, and density can be compared under a range of operating conditions. The initial objective of the investigation was to see whether suitable results can be obtained from the PEPT technique when testing an existing iron ore jig feed.

A batch jig was used with a cylindrical jigging chamber with an inside diameter of 160 mm. The pulse was generated by a PowerRod Linear Actuator (PRA), which offers better control compared to air cylinders by making use of a magnetic drive to propel the cylinder rod.

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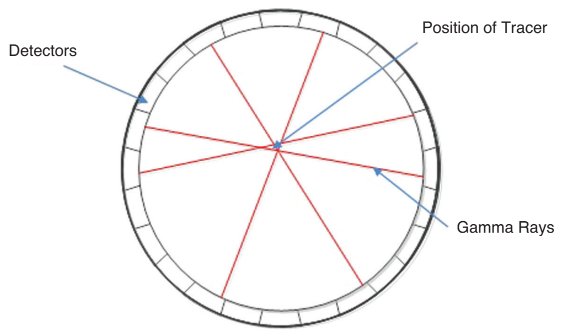

Figure 1—Cylindrical arrangement of detectors in a positron emission tomography camera

Experimental

The iron ore sample was screened to 5–8 mm to minimize the effect of size. Initial test work was conducted to obtain information on the density distribution. The sample was jigged for 10 minutes, after which it was removed in layers and the density of each layer was analysed. The results are shown in Figure 2.

Tracer particles were selected from the sample. Their density and size was measured, and a small hole was drilled in each particle to accommodate the radio-isotope. Before each series of test runs commenced, the tracers were prepared by inserting Ga^{68} isotopes inside the iron ore tracer particle. The half-life of Ga^{68} allowed a six-hour window for test work on one tracer. The jig was filled to a bed height of 140 mm, which corresponded to approximately 8 kg of iron ore. The tracer was then placed in position and water was added to ensure that there was at least 50 mm of water above the jig bed during the entire jig cycle.

The only variables that were changed during these tests were the tracer particle shape, size, density, and starting position. Operating conditions of the jig are shown in Table I. The conditions chosen were based on preliminary test work and gave sufficient separation within the practical time frame. Four different tracers at various starting positions were tested. Table II shows the properties of the tracers.

Results and discussion

The results that follow represent typical results obtained during the tests.

General stratification

The top and side view of the jigging chamber are shown in Figure 3, with the trajectory of a tracer particle (density 5.01). To view the movement of the particle more clearly, the pulse movement of the particle is subtracted from its trajectory by using a background correction technique similar to that used during XRF data analysis. The particle started at the top of the chamber and moved down the vertical axis until it reached the bottom, where it started to move randomly in the horizontal plane.

From the three-dimensional data, the most important movement component for modelling purposes is the vertical component. Figure 4 shows the vertical movement of the tracer particle *versus* time. The first important feature of this

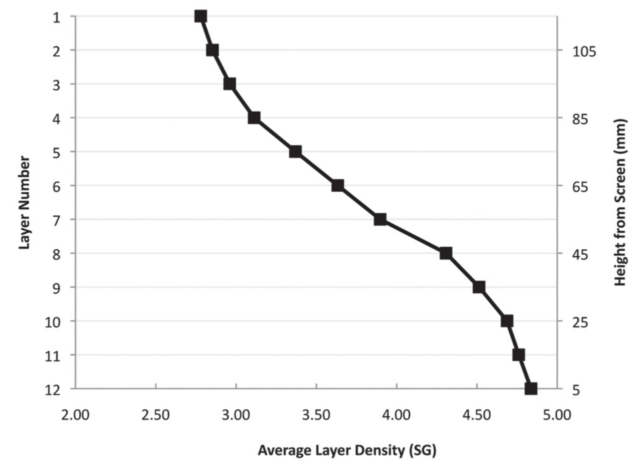

Figure 2—Density profile after stratification

Table I

Jig operating parameter

Pulse height	35 mm
Upward pulse velocity	300 mm/s
Top hold time	160 ms
Downward pulse velocity	100 mm/s
Bottom hold time	100 ms
Run time	10 min

Table II

Properties of tracers

Tracer	1	2	3	4
Density (SG)	5.01	2.92	4.11	3.99
Weight (g)	1.20	0.63	1.24	1.51
Size (mm)	6.53	5.39	4.15	6.65
Shape	Equant	Tabular	Bladed	Equant

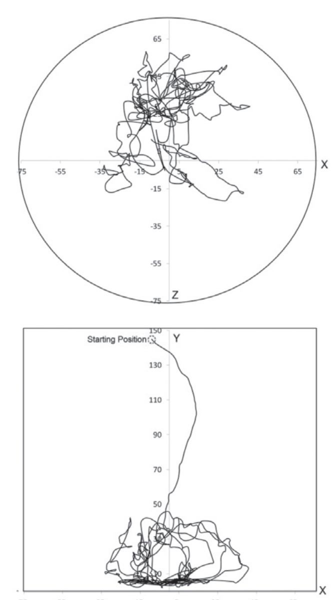

Figure 3—Movement of a particle (density 5.01) inside a batch jig

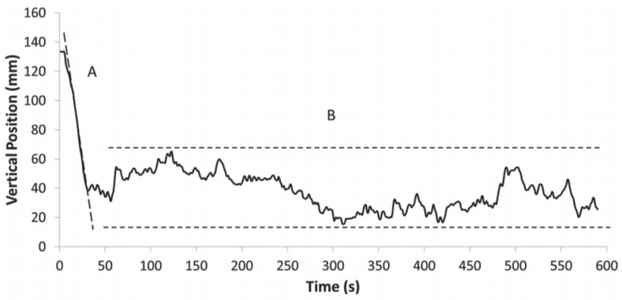

Figure 4—Vertical movement of a tracer particle (density 3.99)

curve is the initial movement of the tracer. The slope of this line gives an indication of the stratification rate of the tracer. Unfortunately, the data-set was too small to draw any conclusion on the effect of different variables on the stratification rate. The second important feature is the movement of the particle after it has reached its stratification position. The tracer will continue to move up and down in a band along the vertical axis (Figure 4, curve 'B'). A frequency plot of the tracer position in this region forms a normal distribution around a centre point, providing the statistical probability of where the tracer will end up.

Individual pulse

The resolution obtained from the PEPT camera is high enough to observe the tracer movement during a single pulse. The particle starts settling as soon as the upward pulse ends (Figure 5); about halfway down the particle seems to stop and remains stationary for about 100 ms. This is probably due to the 'kickback' that the particle experiences from the jig – the initial downward movement of the particle bed exerts a force on the piston that pushes it back slightly. The piston pushes back to produce an upward flow that causes enough drag on the bed to hold it stationary for a short time before the bed moves again. When the particle is at the bottom of the bed this effect is not evident (Figure 6); the particles at the bottom of the jig are not trapped within the bed and can settle even against the slight upward flow from the kickback.

Effect of starting position

There is a definite difference in the behaviour of tracer particles started at different positions in the jig bed. The following cases were considered: a high-density particle (density 5.01) with two starting positions, at the top centre and top side of the bed, and a low-density particle (density 2.92) with centre and side positions at the bottom of the bed. To investigate the effect of starting position on the stratification rate, the time to the final equilibrium position was noted (Table III). The settling rate for the heavy particle started at the sidewall is significantly lower than that of the particle started at the centre. There is no clear difference in settling rates seen for the lighter particle.

Another interesting phenomenon observed when comparing the movement of the tracers from different starting positions is illustrated in Figure 7. Heavy particles starting at the side of the jig chamber have a tendency to move to the centre as they settle, and light particles started at the centre on the bottom move to the side. This indicates that a secondary flow field is generated in the jig, as suggested by the results obtained by Williams *et al.* (1998), who

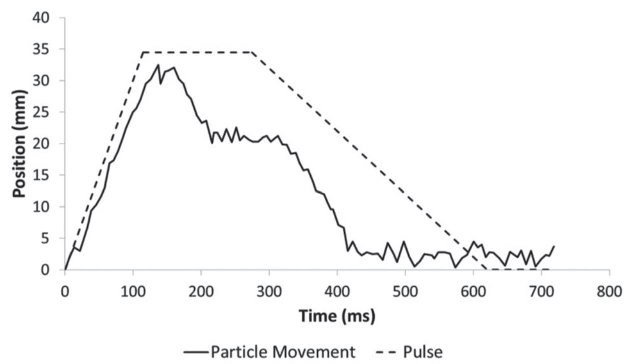

Figure 5—Jig pulse and particle movement with time

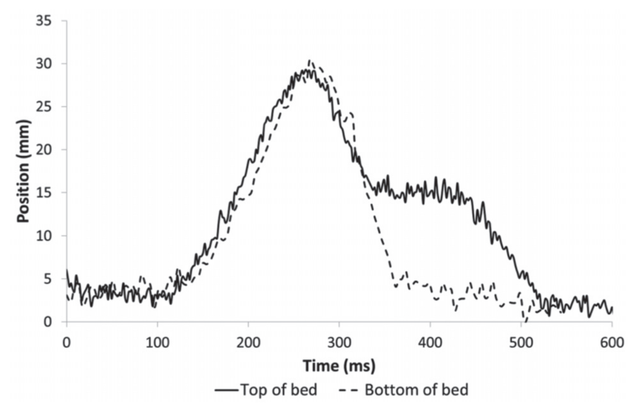

Figure 6—Particle movement with time at the top and bottom of the bed during a single pulse

Table III

Time to stratification at different starting positions

	Time to equilibrium position (sec)			
	Density 5.01 (top centre)	Density 5.01 (top side)	Density 2.92 (bottom centre)	Density 2.92 (bottom side)
Test 1	75	150	63	50
Test 2	63	144	50	50
Test 3	83	122	45	44
Test 4	50	110	25	44
Average	68	132	46	47
Standard deviation	14.5	18.7	15.8	3.5

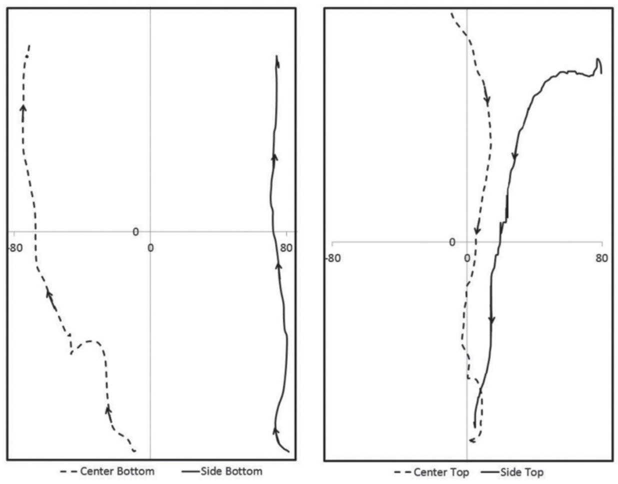

Figure 7—XY plane of the jig. (a) Movement of light particle, (b) movement of heavy particle

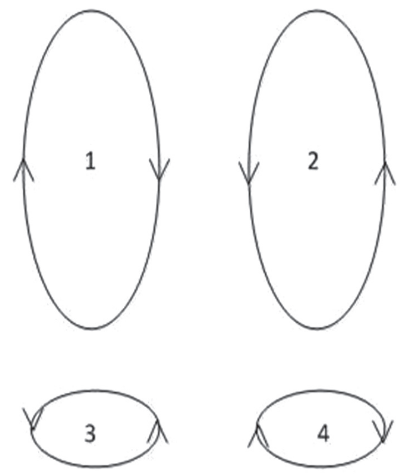

Figure 8—Diagram of flow patterns in the XY plane (Williams *et al.*, 1998)

discovered these flow patterns in a laboratory-scale jig using glass beads, with one of the beads containing the PEPT tracer. The flow fields discovered by Williams *et al.* (1998) shown in Figure 8 can explain some of the behaviour observed in this experiment. The heavy tracer at the side experiences a secondary upward flow that slows its stratification rate. Surprisingly, this effect is not observed to the same extent on the light tracer, which indicates that there are other factors involved.

Jigging is widely used in the mineral processing industry due to its low cost and simplicity of operation. However, jigging lacks the separation efficiency of some of the available technologies such as dense medium separation. For jigs to remain a viable option, their separation efficiencies have to be improved. This can be done either by intelligent operation based on the properties of the feed material or by optimizing the physical design of the jig. This study shows that PEPT should be able to provide data that can be used in generating models that will be useful for both design and operation of jigs.

Optimizing jig design can be an extensive exercise, since physical changes have to be made, which is typically done only when a serious problem arises; In the future, numerical modelling (discrete element modelling and computational fluid dynamics) will make jig design a much easier task, and the kinetic information (Figure 4) generated from PEPT is the ideal data to use when developing such models. PEPT might be able to aid in the development of material-specific models to predict retention time, and possibly efficiency, from data obtained on the feed material. These models can be very useful from an operational standpoint.

Conclusion

Test work on a laboratory jig using PEPT technology shows significant promise for improving understanding the jigging process. It provides new insights into a very ancient technique and presents the opportunity to re-evaluate old theories and develop new ones. The data generated by the PEPT technique can be used to validate theoretical models and to provide insight into specific industry problems, since a real ore can be tested. The resolution from the PEPT technique is such the movement of a particle can be tracked during an individual pulse of the jig. The particle trajectories suggest that there exist additional factors that strongly affect stratification, which require more consideration during further studies.

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