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Particle flow visualization in quartz slurry inside a hydrocyclone using the positron emission particle tracking technique

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ABSTRACT

For the past 120 years, hydrocyclones have been used a wide variety of industrial applications, with their main use in mineral processing being as a classifier. Hydrocyclone characterization relies heavily on empirical and phenomenological models. There is a need to develop a method by which the flow patterns can be quantified under industrial conditions. Positron emission particle tracking (PEPT), developed by the University of Birmingham in the late 1980s, has proven to be a powerful in situ visualization tool for engineering applications. This paper presents data on the motion of quartz particles in a two-inch hydrocyclone using the PEPT technique. Quartz tracer particles were labeled using the direct activation technique. The particle size range was between −2000 and +150 μm which illustrates the flow pattern of particles reporting to the underflow.

1. Introduction

Hydrocyclones are widely used in industrial processes with their main use in mineral processing being as a classifier. They are deceptively simple processing units as they have no moving parts, however, their performance is complex and difficult to predict. The feed enters tangential to the hydrocyclone body under pressure which establishes the primary outer spiral which flows downwards towards the apex forming the underflow. A secondary spiral is set up simultaneously rotating upwards to the vortex finder forming the overflow. These two spiral flows make up the main flow pattern. The classical theory considers that orbiting particles within the flow pattern are subjected to two opposing forces – an outward centrifugal force and an inward drag force. Faster settling particles will move towards the outer wall of the hydrocyclone where the primary spiral flow takes them to the apex while slower settling particles move towards the secondary spiral which takes them to the vortex finder. The centrifugal field of the hydrocyclone flow is superimposed by an intensive and rapid mixing effect, mainly caused by the macroturbulence of the flow (Schubert, 2010). The turbulence level within small hydrocyclones is strongly affected by the rotation of the flow (Dyakowski and Williams, 1993).

The internal flow of the hydrocyclone is complex and remains a challenge to visualize under practical, i.e., opaque, conditions. Positron emission particle tracking (PEPT), developed at University of Birmingham in the 1980s, has been successfully used to visualize flow in a number of unit operations. These include: mixing vessels (Barigou, 2004; Marigo et al., 2013); fluidised beds (Van de Velden et al., 2008); tumbling mills (Bbosa et al., 2011; Volkwyn et al., 2011); and more recently in flotation cells (Waters et al., 2008; Fan et al., 2009; Cole et al., 2010) and spiral concentrators (Waters et al., 2012). The strength of PEPT is that opaque systems can be investigated whereas previous tracking methods require direct visualization of particles (Dabir and Petty, 1986; Hsieh and Rajamani, 1988; Jirun et al., 1990; Monredon et al., 1992; Fisher and Flack, 2002 Lim et al., 2010; Marins et al., 2010). The research presented in this paper is the visualization of real-time flow of a particle inside a two-inch hydrocyclone by the PEPT technique.

Recently, Chang et al. (2011) reported the underflow trajectory of a single resin bead particle labeled with ion-exchange technique inside a hydrocyclone using PEPT. The main drawback to their work from a mineral processing point of view is the lack of a slurry system.

This paper tracks a quartz particle in a slurry system under a closed loop system. The tracer particle is of the same type of

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material as the rest of the system and enters the feed inlet without any preferential orientation. Running the system on a 100% recycle allowed multiple passes of the tracer through the PEPT camera.

2. Materials and methods

2.1. Apparatus and procedure

The test rig was a two-inch diameter Mozley standard hydrocyclone with quartz. The total height of the hydrocyclone was 376.5 mm with the inlet height was 36.5 mm, the conical body height was 300 mm and the apex height was 40 mm. The slurry was re-circulated until the desired pressure was stabilized. The quartz tracer particles were introduced into the sump tank. A summary of the test conditions and settings is shown in Table 1. Measurements were made in the presence of an air core at ambient atmospheric conditions. The inlet flow rate was adjusted by the by-pass valves.

2.2. Tracer particles

The tracer particles were two size classes of quartz activated using the direct labeling technique (Fan et al., 2006a,b). The coarse run used a −2000 + 1700 μm quartz tracer particle labeled with 4×10^{9}–1×10^{10} Bq of ^{18}F via the direct activation mechanism. The creation of the fine particle was through the breakage of a larger particle, followed by screening and selection as described by Boucher et al. (2014).

One kilogram of quartz was added to 25 L of water (3.8% solids by mass) in a sump tank. Prior to adding the tracer, the system was operated until the pressure stabilized. By re-circulating multiple passes over the lifetime of the tracer built up the average flow pattern. The two size classes of quartz tracer are above the approximate cut-size of the two-inch hydrocyclone (20–50 μm), i.e., under the experimental conditions the tracer particles should report to the underflow (Chandrasekhar and Raghavan, 2004).

2.3. Positron camera

The University of Birmingham ADAC Forte positron camera was used to track the trajectory of the tracer particles (Parker et al., 2002). The PEPT geometry with respect to the camera detectors is that the *x*-axis is from the back of the detector to the front, the *y*-axis is the vertical and the *z*-axis is across the front, from left to right. The 3D trajectory is obtained by the triangulation algorithm developed by the University of Birmingham, details of which can be found in Leadbeater and Parker (2009) and Leadbeater et al. (2012).

3. Results and discussion

3.1. Coarse tracer particle

Throughout the experiment, the coarse quartz tracer particles passed through the detector field of view. This allowed the camera to capture the fast moving particle in the primary vortex. The results of a run consist of a set of single particle locations in 3D with time.

Table 1
Test conditions and settings.

Vortex finder diameter (mm)	Apex diameter (mm)	Sump tank volume (L)	Pressure bar (psi)
14	4.7	25	20–35

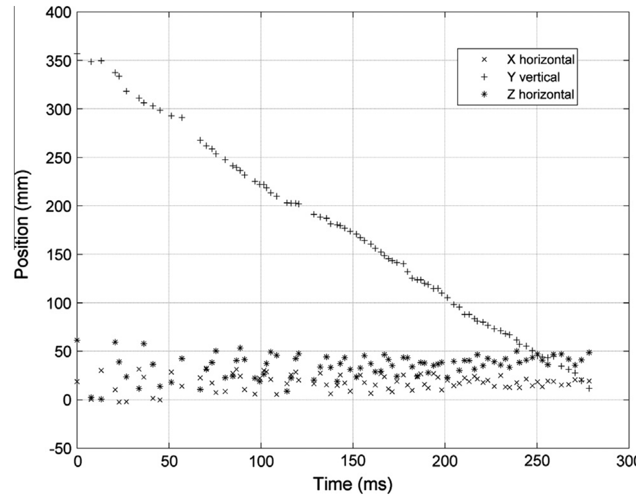

Fig. 1. *X*, *Y* and *Z* position for coarse quartz particle run for a typical pass: $f = 0.05$; $N = 250$.

A typical pass for the coarse quartz tracer particle is shown in Fig. 1 inside the standard two inch hydrocyclone reporting to the underflow. Fig. 2 shows the trajectory for pass one, the grayscale gradient shows the time from the particle entering the field of view and exits. The particle enters through the feed inlet at $t = 0$ and rotates downwards along the hydrocyclone wall in a counterclockwise direction. The diameter of the vortex decreases as the particle moves into the cylindrical section of the hydrocyclone and tapers within the conical section of the hydrocyclone in its downward progression towards the apex.

From Fig. 2, the conical section at between $y = 300$ and $y = 50$, the particle no longer has a continuous downward trajectory but

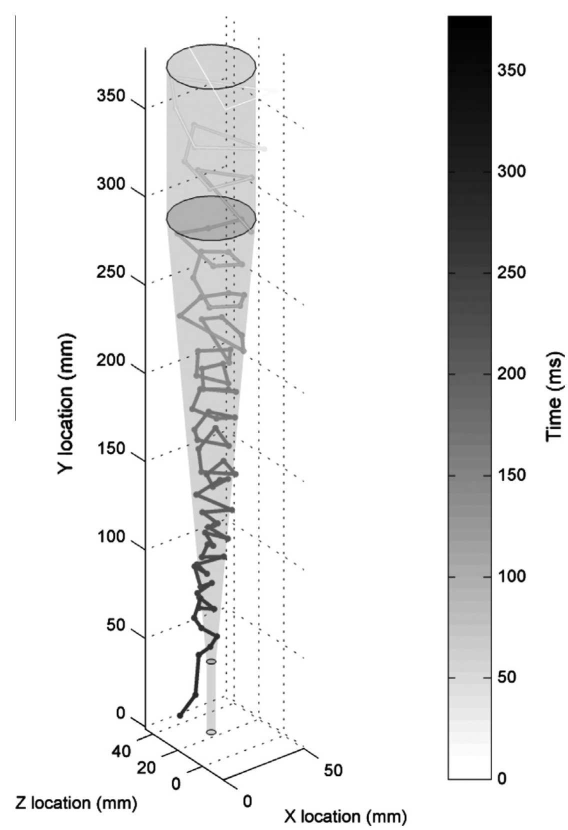

Fig. 2. Trajectory of coarse quartz particle run for a typical pass, with the particle reporting to the underflow: $f = 0.05$; $N = 250$.