Particle flow in a hydrocyclone investigated by radioactive particle tracking

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Abstract
A single particle in a hydrocyclone has been tracked with high temporal and spatial resolution by detecting and cross-triangulating the back-to-back gamma-ray emissions resulting from decay of a radioactive labeller. The trajectory reveals instability in the path of the centrifuged particle in the course of swirling down to the underflow outlet of the hydrocyclone. By following the particle motion, a phenomenon appearing to be the "end of vortex" is observed low in the cyclone.

Keywords. Hydrocyclones – radioactive particle tracking – positron emission particle tracking (PEPT).

INTRODUCTION
Cyclones are one of the most widely used devices for phase separation. Cyclones handling mixtures wherein liquids constitute the continuous phase are referred to as hydrocyclones. Cyclones are characterized by the performance, e.g. the grade efficiency, the overall efficiency, and the overall pressure loss, and it is of great importance to further the understanding of the basic phenomena which have impact on the performance. Tracking a single particle as it moves through the cyclone is the most straight-forward measure to perceive the separation mechanism and potential problems, which are essential for theoretical model formulation and design improvements.

Phase Doppler anemometry (PDA) is one way of acquiring the velocity of a particle in a cyclone by detecting the laser light scattered by a particle at two angles (e.g. Obermair et al., 2005). The technique, which is the focus of this paper, is to trace a radioactive particle three-dimensionally, referred to as positron emission particle tracking (PEPT). This technique has till now been restricted in terms of temporal resolution and particle size, but further developments (Hoffmann et al., 2005; Griffiths et al., 2009) make it possible to apply the technique to cyclone study. Here we report, for the first time, tracking a radioactive particle in a hydrocyclone by detecting and cross-triangulating back-to-back gamma-ray emissions.

METHODS
To label the particle, the $^{18}O(p,n)^{18}F$ reaction is conducted to produce ^{18}F ions. Fan et al. (2006) reported that strong-base anion exchange resins are superior to weak-base anion exchange resins regarding radioactivity uptake because the affinity of ^{18}F ions to the strong-base anion resins is stronger. It is also reported that the radioactivity in a single bead is dependent on the ^{18}F concentration in the solution into which the particles is immersed and the immersion time, i.e. when the immersion time exceeds 25 minutes, the decay rate is greater than ^{18}F exchange rate, and the radioactivity on the particle starts to decrease. Here the strong anion exchange resin beads "Amberlyst A26 Hydroxide Form" (Thermo Fisher Scientific Inc.) with sizes from 400 to 700 µm are used, being immersed into water containing ^{18}F. The mixture is shaken for about 10 minutes for radioactivity uptake. By this procedure the activities of the resin beads can reach 450-1440 µCi. During hydrocyclone operation, the radioactive bead is injected upstream of the inlet. After the operation is terminated, the final position of the bead is confirmed by a dosimeter.

The radioactive decay of ^{18}F causes the emission of a positron and a neutrino. The positron, moving through the medium, annihilates with an electron, which results in the back-to-back emission of two gamma photons. The emitted photons are detected by scintillating crystal sensors of Siemens TruePoint scanner. The scanner consists of three rings of 48 sensor blocks. Each block has 13x13 crystals. The two photons are considered to have been emanated from one annihilation, if they are detected within a narrow time window. A "line of response" (LOR) can be drawn between the two detectors, whose positions are stored in "list mode format." The algorithm developed to narrow the window containing the cut-points of LORs used by Hoffmann et al. (2005) was refined and implemented using a FORTRAN program.

RESULTS

Analysing one-minute data from a stationary particle in water, computing one position per millisecond, gives the standard deviation of 0.2 mm or less, which confirms sufficient tracer activity and the efficacy of algorithm. That the number of effective cut-points of LORs does not drop and the scatter does not increase in time shows the radioactivity does not leach off the particle during the hydrocyclone operation.

Measurements of the settling velocity of the tracer particle in the field of gravity confirms that the Stokes diameters of the particles are higher than the cut size for this hydrocyclone design, and thus the particles are presumed to be separated out.

As the coordinates of the particle are determined using the algorithm and the in-house program, both the trajectory and animations of the moving particle can be drawn, allowing us to investigate the path of the particle in detail. Figure 1 shows the trajectory of the radioactive particle in the hydrocyclone. The temporal resolution, i.e. the time between adjacent points, is 1 millisecond. The particle moving from inlet to underflow outlet takes less than 3 seconds. The animation of a moving particle shows that, rather than directly swirling through the cyclone from inlet to underflow chamber, the particle turns and whirls upstream at some stages, rotating, as it does so, at a smaller radius and higher speed. The particle seems to be swept into the inner, upward flowing, part of the vortex for a while, and later centrifuged outward to the downwardly directed vortex again. In some sections, where the trajectory is denser in Figure 1, the turn-back process occurs even more than ten times. The animation also shows the possible occurrence of the "end of vortex phenomenon," which was described by Hoffmann et al. (2007).

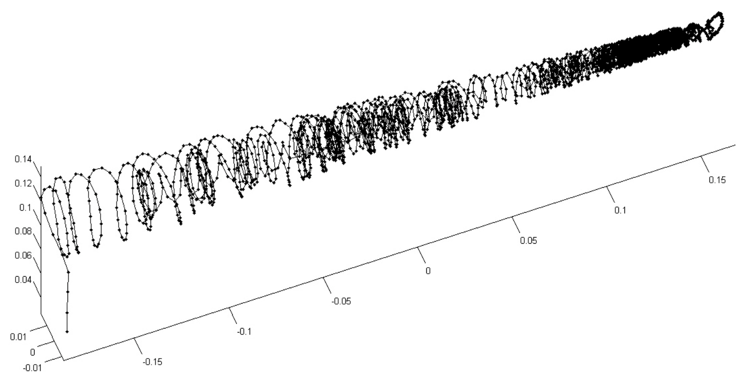

Figure 1. The trajectory of a radioactive particle in the hydrocyclone

CONCLUSION

This work has described a technique to precisely follow a fast-moving particle in a hydrocyclone. The particle labelling method and the data analyzing algorithm are developed and verified. Following the particle motion reveals phenomena which are difficult or impossible to discover by other measurement techniques, e.g. the end of vortex, and the particle's wandering between the inner and outer vortex. This provides the opportunities for directly studying the instability in hydrocyclones of various geometries and under various operating conditions.

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