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Experimental investigation of various inlet section angles in mini-hydrocyclones using particle imaging velocimetry

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ABSTRACT

Recent research has investigated the ability of mini-hydrocyclones to achieve high separation efficiency. Previous studies of hydrocyclones focused mainly on the hydrocylinder, cone, vortex finder, and outlet dimensions. Some parameters have proven to be optimal for increasing the separation efficiency, but these parameters are not sensitive to the shortcut flow rate, which is the main factor preventing further increases in separation efficiency. The inlet section angle greatly affects the shortcut flow, but research on this topic has been limited. Previous studies have used computational fluid dynamics (CFD) to investigate the flow structure inside mini-hydrocyclones instead of using direct measurements. In this study, particle image velocimetry (PIV) was used to measure the flow pattern in a set of 35 mm mini-hydrocyclones with different inlet section angles (0°, 30°, 45°, and 60°). We measured the axial velocity and radial velocity distributions of the entire test zone in the mini-hydrocyclones, constructed streamline diagrams calculated from the vectors, measured the shortcut flow rate, and calculated the separation and grade efficiency of the four inlet section angles. Our results indicate that the inlet section angle may effectively improve separation performance. In addition, at the same inlet velocity, both separation efficiencies and grade efficiencies increase with increasing the inlet section angle. The results also suggested that the optimal inlet section angle is 30° for the series of mini-hydrocyclones investigated in this study.

1. Introduction

For more than 100 years, hydrocyclones have been used in mineral processing [1], petrochemical [2], environmental [3], and other industries for purposes such as particle separation, classification and thickening. Because the miniaturization of hydrocyclones greatly improves the separation precision at micron and submicron scale [4], the applications of mini-hydrocyclones have expanded to many new fields, such as biology [5,6], fisheries, aquatic sciences [7,8], and even submicron or nanometer scale applications [9].

Over the past decades of years, most studies on hydrocyclones have focused on the hydrocylinder, cone, vortex, finder, and outlet [10–13]; little research has investigated the inlet geometry of hydrocyclones. Using computational fluid dynamics (CFD), Hwang [14] compared the effectiveness of various types of hydrocyclone inlets, such as single, dual, and tetrad inlets, as well as hydrocyclone top-plates with a cone shape or guide channel. The results showed that increasing the inlet number and narrowing the inlet width effectively improve the particle separation efficiency. Zhao [15] developed a new kind of cyclone with symmetrical spiral inlets (SSI), including a direct symmetrical spiral inlet (DSSI) and a converging symmetrical spiral inlet (CSSI). He discovered that the SSI, especially the CSSI inlet geometry, significantly increases the collection efficiency while insignificantly increases the pressure drop. Because increasing the section angle may eliminate shortcut flow, some research [16,17] has used CFD to investigate the separation characteristics with a range of inlet section angles. However, in order to fully understand how the inlet section angle affects the separation performance of the hydrocyclone, an experimental study is required.

Particle image velocimetry (PIV), a non-intrusive visualization technique, can detect an entire velocity field simultaneously. In contrast, other traditional methods, such as Pitot tubes, hot-wire anemometers (HWA), laser Doppler anemometry (LDA), and phase Doppler particle analyzer (PDPA), only measure one point at a time. Using the PIV method, we may gain a deeper understanding

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Nomenclature

a	inlet height (mm)
b	inlet width (mm)
d_o	inner diameter of vortex finder (mm)
d_u	inner diameter of underflow orifice (mm)
D	nominal diameter (mm)
D_o	outer diameter of vortex finder (mm)
H	height of conical body (mm)
L	height of cylindrical body (mm)
Q_i	inlet flow rate (m^3/h)
S	depth of vortex finder (mm)
V_i	inlet velocity (m/s)
V_r	radial velocity (m/s)
V_z	axial velocity (m/s)

Greek letters

α	inlet section angle
μ	water viscosity (Pa s)
ρ	water density (kg/m^3)

of the flow fields in hydro-cyclones from a global perspective. Unfortunately, the application of PIV for studying the flow field in hydrocyclones has been limited.

We experimentally investigated the separation efficiencies of mini-hydrocyclones and analyzed the effects of the inlet section angle on the separation performance. We further explored the mechanism by which the inlet section angle improves the separation performance.

2. Experimental setup

2.1. Schematic diagram

A schematic diagram of the experimental apparatus is shown in Fig. 1. Water was mixed with tracer particles and fed into the pipeline through a centrifugal pump. To reduce fluctuations in the flow rate and pressure, a bumper tank was set. Flow rates were measured by flow meters and controlled by shut-off valves. The changes in pressure through the mini-hydrocyclones were monitored by several pressure gauges. A thin laser light sheet was used to interrogate the flow field, illuminating tracer particles. Images containing the flow information were recorded using a CCD camera and transferred to a computer for analysis.

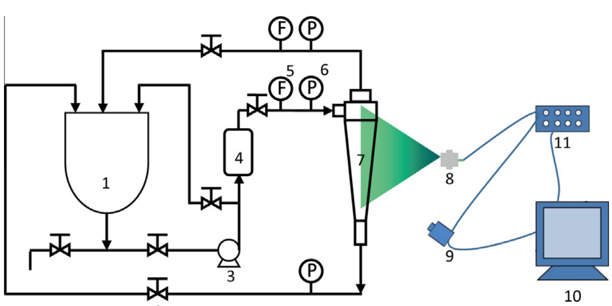

Fig. 1. Schematic diagram of the experimental setup. 1 – Feed tank; 2 – shut-off valve; 3 – centrifugal pump; 4 – bumper tank; 5 – flow meter; 6 – pressure gauges; 7 – mini-hydrocyclone; 8 – dual YAG laser; 9 – CCD camera; 10 – computer system; 11 – synchronizer.

2.2. Mini-hydrocyclones

A series of mini-hydrocyclones with four inlet section angles (0°, 30°, 45°, and 60°) and a diameter of 35 mm were investigated.

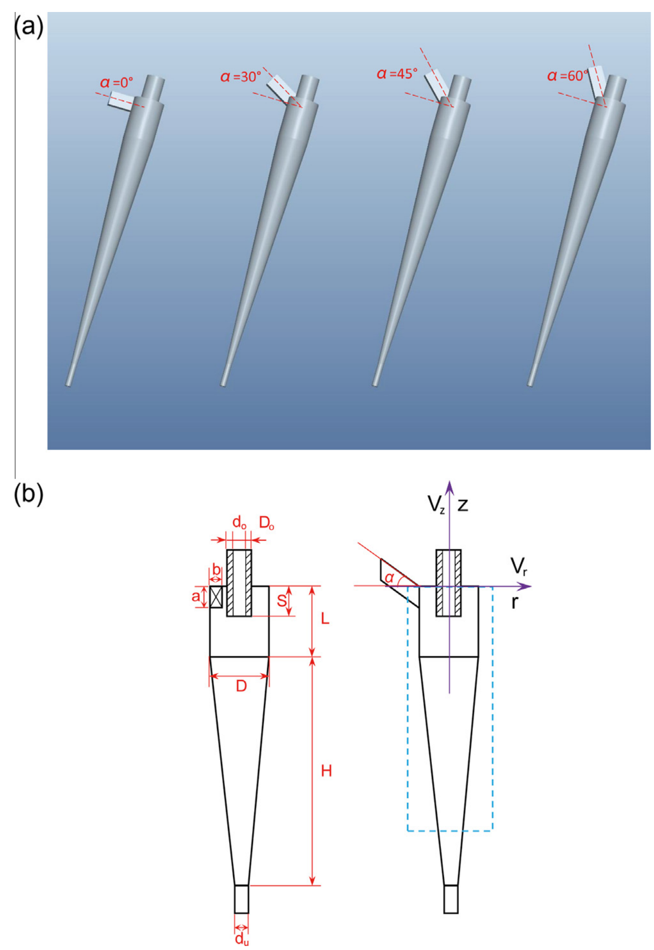

Fig. 2. (a) Hydrocyclone outline view and (b) hydrocyclone geometry.

Table 1
Dimensions of the mini-hydrocyclones.

Hydrocyclones	α (°)	D (mm)	$a \times b$ (mm)	L/D	H/D	S/D	d_o/D	D_o/D	d_u/D
I	0	35	8.4 × 5.6	1.48	7.37	0.57	0.24	0.68	0.08
II	30								
III	45								
IV	60								