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Experimental study of circulation flow in a light dispersion hydrocyclone

Yi Liu, Qiang Yang, Peng Qian, Hua-lin Wang [*]

State Environmental Protection Key Laboratory of Environmental Risk Assessment and Control on Chemical Process, East China University of Science and Technology, Shanghai 200237, PR China

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ABSTRACT

The circulation flow, in light dispersion hydrocyclones and the effects of various parameters on this flow were studied quantitatively through measurements of the axial velocity field. A phase Doppler particle analyzer (PDPA) system was developed to measure the axial velocity field in axial cross sections in ∅ 35 mm hydrocyclones with various vortex finders lengths, overflow orifice diameters, cone angles, inlet flow rates, and split ratios. The results showed that the zero-axial-velocity wave zone (ZAVWZ), which is responsible for the coupling of circular and closed flow in most axial cross sections, is caused by the velocity gradient and can be described as the location of the circulation flow. The mechanism of circulation flow and cyclone separation was revealed by the formation mechanism of the circulation flow. A new equation for calculating the circulation flow rate is proposed. By studying the effects of the geometric and operating parameters on the circulation flow, it was observed that smaller distribution areas and rates of circulation flow usually result in higher separation efficiency in a hydrocyclone.

1. Introduction

A better understanding of the multiphase flow pattern in a hydrocyclone is of paramount importance to achieving the best separation performance and the lowest economic cost. Typically, studies of flow pattern have focused on the combination of the inner and outer vortexes [1,2], the velocity and pressure distributions [3,4], the precession or elimination approach of air core [5–8] and the short-circuiting flow [9,10]. These studies surveyed nearly all of the flow patterns in hydrocyclones and discussed the effects of these flow patterns on the separation efficiency, which are all available for geometric and operating parameters design guidance. Consequently, more attention should be paid on circulation flow rather than few studies at present.

The circulation flow is very complicated because of the presence of swirling turbulence, the air core, and the movement of its distribution area [11,12]. In the past, experimental studies attempted to gain insight into the circulation flow through comparisons between traditional hydrocyclones and those with cone-shaped top plates. These studies demonstrated that the latter reduce the fine particle circulation area near the outer surface of the overflow conduit and significantly improve the separation efficiency for fine particles [13]. In addition, these studies found that the circulation flow decreases with increasing cone angle in hydrocyclones with a conical top-plate, and therefore the tangential velocity and the centrifugal effect near the hydrocyclone wall increase [14]. These studies mainly focused on a qualitative analysis of whether the circulation flow benefits the separation performance providing only a basic understanding that is inadequate for the design of hydrocyclones for industrial applications [15–17]. Refs. [1,18] simply determined that the circulation flow in hydrocyclones does not promote separation, and Refs. [19–21] located the general area in which the circulation flow exists. More axial velocities are required, particularly along the inner wall of the cylindrical section and the outer wall of the vortex finder, to ascertain the specific boundaries and flow rate of the circulation flow. Previous work concerning optimization of the geometric parameters included measurements of the three-dimensional velocities in various axial cross sections in ∅ 35 mm hydrocyclones using PDPA [22,23]. But the inlet port and the vortex finder obstruct the optical path preventing measurements of the axial velocity distribution, which is largely responsible for the formation of circulation flow.

In this study, PDPA was used to investigate the variation in the axial velocity region in axial cross sections of the cylindrical section and the upper area of the conical section of a ∅ 35 mm light-dispersion hydrocyclone. The boundaries of the circulation flow and the variation in the flow rate were then explored. Starting from the optimal values of the geometric and operating parameters [22,23], differences of the circulation flow in the hydrocyclone was

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[*] Corresponding author at: Environmental Protection Key Laboratory of Environmental Risk Assessment and Control on Chemical Process, East China University of Science and Technology, 130 Meilong Road, Shanghai 200237, PR China. Tel.: +86 21 64252748; fax: +86 21 64251894.

E-mail address: samwhl@163.com (H.-l. Wang).

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studied as varied individual parameters. Therefore, the relationship between the characteristics of the circulation flow and separation performance, with optimized geometric and operating parameters was identified.

2. Experiments

2.1. Geometric parameters of a hydrocyclone

The light-dispersion hydrocyclone studied by Ma [22] and Liu [23] and similar devices were selected for the experiments. The parameters of the optimized design are listed in Table 1; and the sight windows for PDPA in the hydrocyclone are shown in Fig. 1. The hydrocyclone has a typical double-tangential inlet and a single cone structure, which is widely used in the separation of a light dispersed phase such as oil in water. The separation efficiency and the energy consumption were verified through experiments. The oil–water separation efficiency can reach approximately 80% with an energy consumption of less than 0.2 MPa when the inlet oil concentration, the inlet flow rate, the inlet pressure, and the split ratio are 300 ppm, 1.2 t/h, 0.35 MPa, and 8%, respectively.

2.2. Experimental procedure

The experimental apparatus for the hydrocyclone flow field tests is illustrated in Fig. 2. An appropriate number of tracer particles were added to the water in the storage tank and thoroughly mixed. The water with the tracer particles was pumped to a buffer tank, which was used to guarantee the stability of the flow field, and then into the hydrocyclone under pressure. Following separation, the overflow and the underflow returned to the buffer tank, and the circulation ended. A buffer tank was connected at the overflow port to further guarantee the stability of the flow field. A bypass for the pump was installed to prevent damage to the hydrocyclone, which is made of acrylic, caused by the starting and stopping of the pump. Valves and other measurement devices were placed at the inlet, the overflow port, and the underflow port of the hydrocyclone. The PDPA was positioned next to the hydrocyclone.

2.3. PDPA measurement

The PDPA was employed to measure the velocity distribution in the hydrocyclone in these experiments. The PDPA measures the properties of particles based on the Doppler effect, i.e., the frequency difference between the light from an illumination source (a laser) and the light reflected (scattered) by moving particles. The principle used by the PDPA for measurement velocity is shown in Fig. 3. The relationship between the particle speed and the frequency difference can be expressed as follows:

$$f_D = f_S - f_0 = \frac{u \cdot (e_S - e_O)}{\lambda} = \frac{1}{\lambda}|u \cdot (e_S - e_O)| \quad (1)$$

f_D: frequency difference between scattering light and incident light;
f_S: scattering light frequency;
f_0: laser wave frequency;
u: velocity of particle;
λ: laser wave length;
e_S: unit vector of scattering light;
e_O: unit vector of incident light.

Table 1
Geometric parameters of the optimized ∅ 35 mm hydrocyclone.

Inlet type	Inlet import	D	Do	*L*	Du	Lc	*θ*
Double	4 × 10	35	3.5	5	8	35	10°

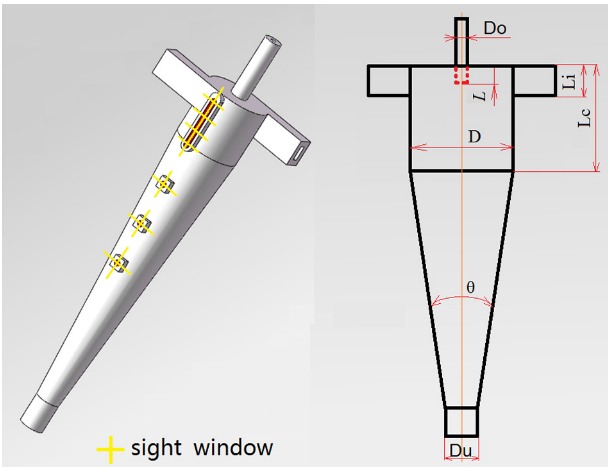
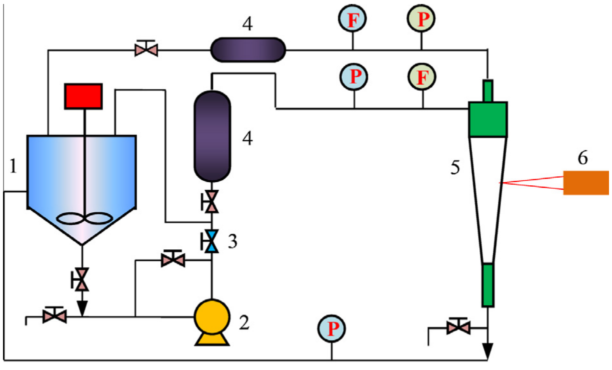


Fig. 1. The sight windows on the optimized hydrocyclone.



1.storage tank; 2.pump; 3.pressure maintaining valve;
4.buffer tank; 5.hydrocyclone; 6.PDPA

Fig. 2. Experimental apparatus.

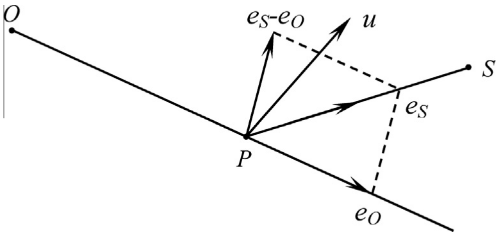


Fig. 3. PDPA velocity measurement principle.

The PDPA measures the speeds of the particles in the fluid, rather than the speed of the fluid itself. The precise tracking of tracer particles by the PDPA provides a guarantee of accurate test data. The diameters of the particles used in the experiment followed a normal distribution with a range of 8–12 μm. Hollow glass beads with a density of 1 g/cm^3 were used as the tracer particles in the continuous phase (water) to ensure the accuracy of the experimental data. In addition, a flume for optical compensation was placed around the hydrocyclone, and a slender sight window allowed measurements to be taken in the cylindrical section in order to avoid the obstruction of optical path during PDPA measurement.