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Research on the Motion of Solid Particles in a Hydrocyclone

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ABSTRACT

By using a new type of laser surveying instrument named the particle dynamics analyzer, the radial and axial velocity components and the size and concentration of solid particles at selected positions within a transparent hydrocyclone were measured directly, and profiles of the solid particle flow field were obtained. Some new observations were made, such as that the maximum concentration was at the loci of zero vertical velocity, and there was separation of some particles in the inner helical flow.

INTRODUCTION

The study of hydrocyclones has a long history, with important applications (1). Unfortunately, because of a lack of measuring methods, there have been few experimental studies on the motion of solid particles in hydrocyclones. Almost all previous experimental work on the flow field in hydrocyclones has focused on the liquid flow. Until now, there have been no definite conclusions about the motion of solid particles in a hydrocyclone. Because the flow field in hydrocyclones is extremely complex, the motion of solid particles in hydrocyclones must be determined experimentally before we can understand the separation mechanism of hydrocyclones and obtain a theoretical foundation for structure optimization and efficiency improvement of hydrocyclones.

A new type of laser surveying instrument named the particle dynamics analyzer (PDA) has become available recently. It can be used to measure the motion of particles in two-phase flows (2). It is a good instrument for research on the motion of solid particles in hydrocyclones.

An experimental study on the motion of solid particles in a hydrocyclone by use of a PDA is described in this paper, and some new observations were made from the experimental results.

EXPERIMENTAL

PDA Principle

The PDA simultaneously measures the velocity, size, and concentration of particles in two-phase flows (2). The instrument is based on phase Doppler anemometry, which is an extension of laser Doppler anemometry (LDA). The velocity is measured in the usual way from the frequency of the Doppler burst. The size measurement is based on comparing the signals from multiple detectors located at different scattering angles. The signals have a phase difference which is linearly dependent on the particle diameter. The concentration is also obtained from these measurements.

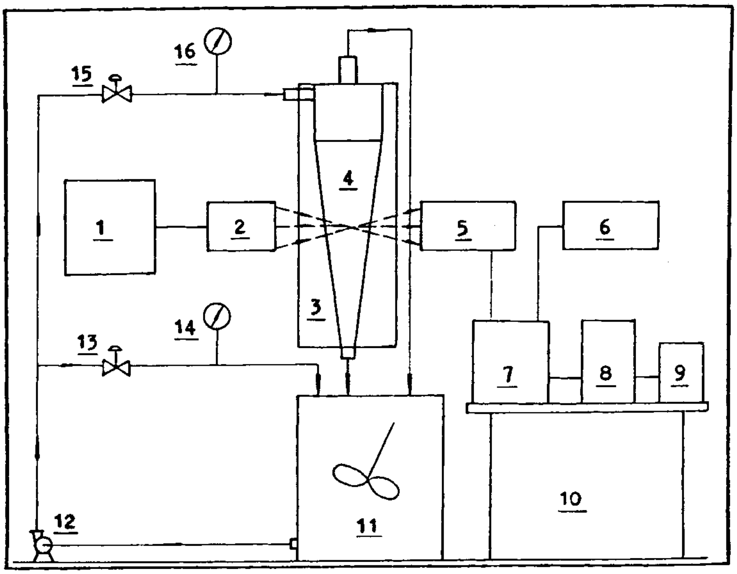

FIG. 1 Apparatus flow chart: (1) laser producer; (2) laser probe; (3) optical compensating box; (4) hydrocyclone; (5) PDA receiving optics; (6) oscilloscope; (7) signal processor; (8) computer; (9) printer; (10) table; (11) water tank; (12) pump; (13), (15) valves; (14), (16) gauges.

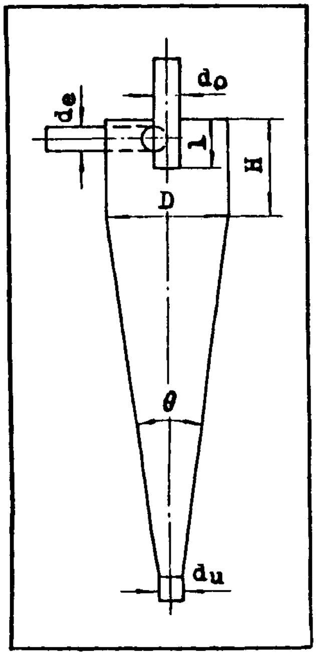

FIG. 2 The hydrocyclone.

Apparatus

The flow chart of the apparatus is shown in Fig. 1.

The hydrocyclone and the compensating box are made of transparent Perspex and polished. The optical compensating box was of rectangular cross section and was filled with water. The geometry of the hydrocyclone is shown in Fig. 2 and listed in Table 1.

TABLE 1
Hydrocyclone Geometry

Geometry	Parameter
D	80 mm
H	70 mm
θ	15°
d_e	14 mm
d_0	16 mm
l	40 mm
d_u	12 mm

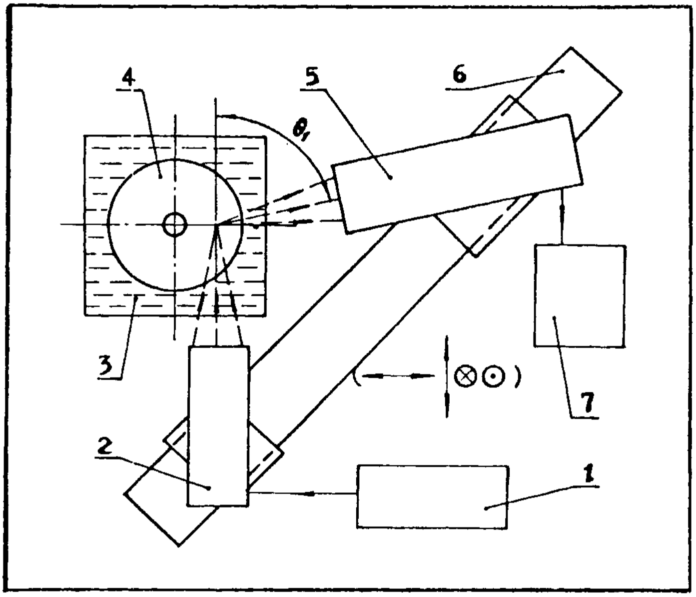

FIG. 3 The optical system of the apparatus: (1) laser producer; (2) laser probe; (3) optical compensating box; (4) hydrocyclone; (5) PDA receiving optics; (6) movable mounting bench; (7) signal processor.

The optical system is given in Fig. 3. The mounting bench 6 could be moved in a three-dimensional Cartesian coordinate system with graduated levers. The angle θ_1 is called the optimum scattering angle. It depends on the type of liquid and particles being measured (2). In the experiment, the liquid was water and the particles were polystyrene. According to the calculation, θ_1 was 80°. The optical error was rectified during measuring.

TABLE 2
The Experimental Parameters

Operation parameter, inlet pressure: P_e (Pa)	Characteristics of solid particles		
	Density (kg/m^3)	Concentration (%)	Size (μm)
3×10^4	1.05×10^3	0.1	154–200

Figure 4 shows the measured points distribution in the hydrocyclone. Because the flow field in hydrocyclones is mostly axial symmetric, we only measured half the field.

The operation parameter and the characteristics of solid particles are given in Table 2.

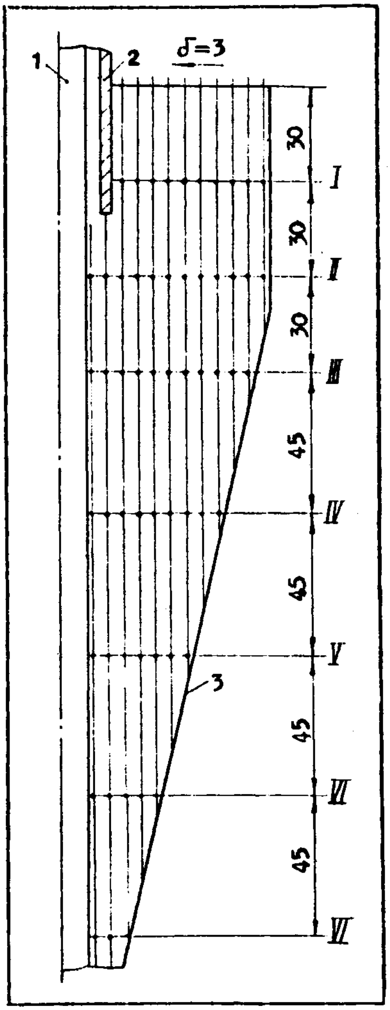

FIG. 4 The distribution of measured points in the hydrocyclone: (1) air core; (2) vortex finder wall; (3) hydrocyclone wall.

RESULTS AND DISCUSSION

Radial Velocity of Particles

As illustrated in Fig. 5 (see Table 3 for the value of each point), the distributions of the radial velocity of solid particles along the radii at several horizontal levels within the hydrocyclone have regularity. In the cone section of the hydrocyclone, the radial velocity increases from the hydrocyclone wall toward the center of the hydrocyclone, reaches a maximum near the air/water interface, and then decreases. The radial velocity gradient in the inner helical flow is larger than that in the outer helical flow. The distribution of radial velocity of solid particles along the radii can be described by the following relationship:

$$V_r \cdot r^m = C \tag{1}$$

where V_r is the radial velocity of solid particles at radius r, and m and C are constants.

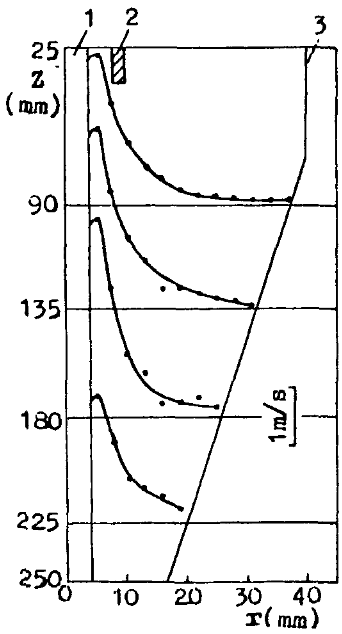

FIG. 5 Radial velocity of solid particles: (1) air core; (2) vortex finder wall; (3) hydrocyclone wall.

TABLE 3
The Radial Velocity Values of Solid Particles at Various Positions

	Z (mm)			
	90	135	180	225
r (mm)	V_r (m/s)			
5	2.490	3.050	3.390	2.160
8	1.660	2.050	2.190	1.350
11	0.969	1.240	1.010	0.670
14	0.578	0.859	0.716	0.595
17	0.457	0.379	0.217	0.495
20	0.233	0.384	0.232	0.280
23	0.154	0.299	0.306	
26	0.130	0.199	0.168	
29	0.101	0.116		
32	0.064	0.054		
35	0.016			
38	0.034			

Axial Velocity of Solid Particles

In the past, the axial velocity of solid particles in hydrocyclones was assumed to be the same as that of liquid. But from Fig. 6 (see Table 4 for the exact values), we found there was a difference between them. [The distribution of the axial velocity of liquid (1) is given in Fig. 7.] This difference is due to the circuit eddy in the upper cone section. Solid particles in the area between the two LZVVs (loci of zero vertical velocity) cannot be separated because they cannot move down to the apex. Therefore, this does not contribute to the separation efficiency of a hydrocyclone. The volume of this region should be reduced as much as possible.

Two-Dimensional Velocity Field of Particles

The profile of velocity field of solid particles in a hydrocyclone is shown in Fig. 8. We found from the profile that solid particles below the bottom of the vortex finder might move along radii toward the hydrocyclone wall. This movement of solid particles demonstrates that not all particles in the inner helical flow will discharge with the overflow, and that some particles in the inner helical flow will enter the outer helical flow below the bottom of the vortex finder and might be separated. The equilibrium orbit theory (1) was based on the assumption that particles in the inner flow discharge with the overflow and that particles in the outer flow discharge with the

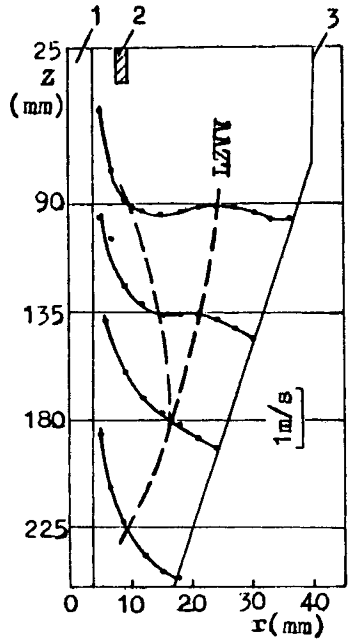

FIG. 6 Axial velocity of solid particles: (1) air core; (2) vortex finder wall; (3) hydrocyclone wall.

TABLE 4
The Solid Particle Axial Velocity Values vs Z and r

	Z (mm)			
	90	135	180	225
r (mm)	V_z (m/s)			
5	−1.530	−1.590		−1.550
8	−0.555	−1.230	−1.610	−0.622
11	−0.058	−0.420	−0.792	−0.029
14	0.183	−0.122	−0.329	0.453
17	0.196	0.043	−0.101	0.735
20	0.122	0.037	0.074	0.865
23	0.086	0.044	0.312	
26	0.080	0.179	0.498	
29	0.086	0.289		
32	0.166	0.418		
35	0.265			
38	0.293			

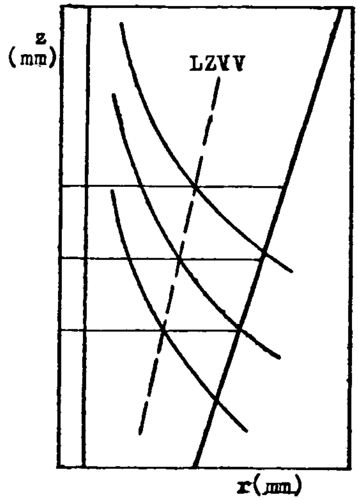

FIG. 7 The axial velocity of liquid within a hydrocyclone (see in Ref. 1).

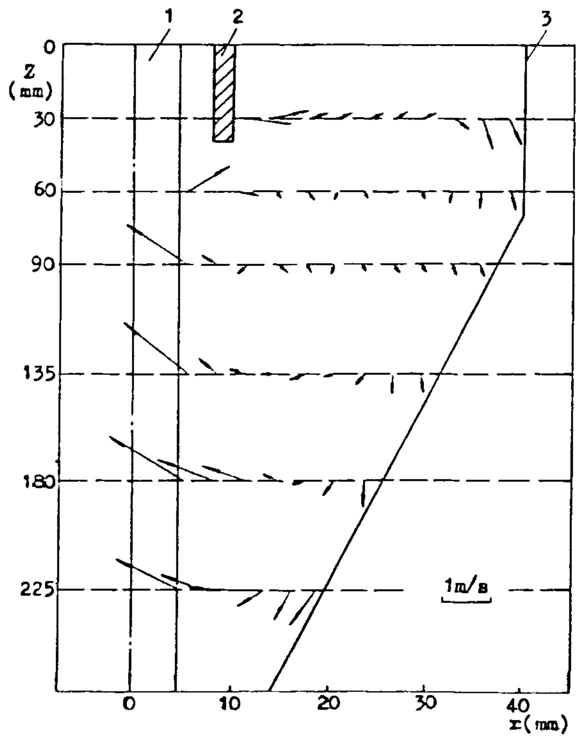

FIG. 8 Two-dimensional velocity field of solid particles: (1) air core; (2) vortex finder wall; (3) hydrocyclone wall.

underflow. However, our experimental results indicate that the equilibrium orbit theory should be modified.

Size Distribution of Particles

Figure 9 shows the distribution of solid particles sizes in a hydrocyclone (see Table 5 for the size values). The size of solid particles increases from the center of the hydrocyclone toward the hydrocyclone wall. This result verifies the previous theoretical study on size distribution.

Concentration Distribution of Particles

The concentration distribution of solid particles in a hydrocyclone is shown in Fig. 10, where the concentration unit is the number of particles per cubic centimeter (see Table 6 for the concentration values). Figure 10 indicates that the concentration maximum is not near the hydrocyclone wall but at the LZVV of solid particles. At the LZVV, the composition of velocity components of solid particles reaches a minimum; therefore, the solid particles have a tendency to accumulate there.

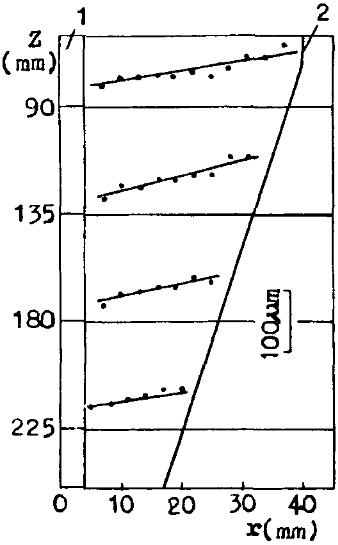

FIG. 9 Size distribution of solid particles: (1) air core; (2) hydrocyclone wall.

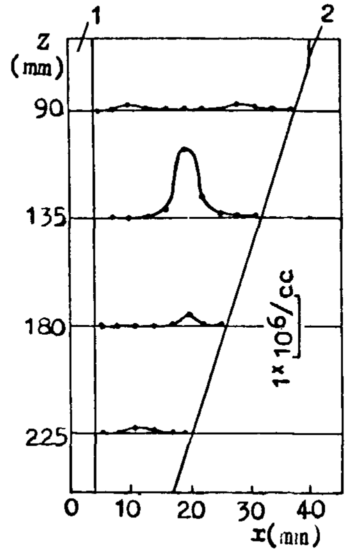

FIG. 10 Distribution of concentration of solid particles: (1) air core; (2) hydrocyclone wall.

TABLE 5
The Size Distribution Values

	Z (mm)			
	90	135	180	225
r (mm)	Size (μm)			
8	35.7	22.8	25.4	44.4
11	52.0	51.1	49.5	50.7
14	54.8	48.1	50.8	53.9
17	57.8	60.1	57.7	69.2
20	54.6	58.9	56.5	70.6
23	59.9	63.3	74.5	
26	56.6	68.7	68.9	
29	65.9	100.0		
32	82.8	100.0		
35	80.1			
38	104.0			

TABLE 6
The Concentration Distribution Values

	Z (mm)			
	90	135	180	225
r (mm)	Concentration (1/cm^3)			
5	1.84E+2		5.00E+2	7.37E+2
8	1.53E+3	86	1.16E+3	5.19E+3
11	6.87E+4	6.07E+2	5.75E+3	9.36E+4
14	1.46E+4	3.81E+3	1.25E+4	3.37E+4
17	2.15E+4	1.05E+5	1.27E+4	4.13E+3
20	2.93E+4	1.11E+6	1.80E+5	2.58E+3
23	2.12E+4	3.88E+5	3.26E+4	
26	8.63E+3	7.68E+4	1.11E+4	
29	7.25E+4	3.25E+3		
32	2.15E+4	1.03E+4		
35	7.22E+2			
38	84			

CONCLUSION

1. A PDA has been successfully used to investigate the motion of solid particles and the separation mechanism in a hydrocyclone.
2. Not all solid particles in the inner helical flow discharge with the overflow, some of them could also be separated. The LZVV is not the absolute boundary for the separation.
3. The size of solid particles decreases from the hydrocyclone wall toward the center of the hydrocyclone.
4. The concentration maximum is not near the hydrocyclone wall but at the LZVV of solid particles.

ACKNOWLEDGMENT

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