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Vortex finder optimum length in hydrocyclone separation

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Abstract

Effectiveness of hydrocyclone separations is highly dependent on their geometrical characteristics such as: chamber dimensions, aperture diameters or feed inlet geometry, for instance. Moreover, slight modifications of any of these features might severely affect separation efficiency. This work highlights the fundamental significance of the position of the vortex finder, showing how small changes in its length have meaningful effects on mass recovery and particle size distribution in overflow and underflow streams. This parameter has been scarcely considered in design studies. In order to establish the importance of the vortex finder length different and complementary methodologies were used such as mass balance, granulometric analysis and efficiency evaluation. Results obtained using theses methodologies were in agreement, showing that the highest efficient length of the vortex finder is 10% of the total length of the cyclone (0.1 L_t). This result was found for two hydrocyclones of different sizes, giving a more consistent conclusion.

Keywords: Hydrocyclones; Particle analysis; Solid–liquid separation; Vortex finder

1. Introduction

Cyclones are widely known in practice, mainly due to their use in particle separation from gaseous streams [1,2]. Applying this basic knowledge to the separation of suspended solids from liquid streams the inertial devices known as “hydrocyclones” appear.

A hydrocyclone is able to separate or concentrate suspended particles from a fluid stream. Nowadays, hydrocyclones are used to separate solid–fluid streams [3] fluid–fluid streams [4,5] and gas–liquid streams [6].

Cyclones are inertial devices that allow separation or concentration due to the difference between inertial forces that induce the movement of suspended solids in a liquid bulk. Unlike conventional centrifuges, which use a similar separation principle, hydrocyclones present many advantages [7,8], such as the absence of moving parts, low energy consumption and low residence time.

Generally, the feed slurry is introduced into the hydrocyclone flowing tangentially to the cylindrical upper zone, allowing a progressive separation of the suspended solids from the feed stream. The separation principle is based on inertial forces, since the circular trajectory induces a radial acceleration. If the density of solid particles is higher than the fluid density, these particles are moved towards the wall and leave the hydrocyclone preferentially through the lower exit. If the particles are lighter than the liquid, they are drawn mainly to the upper exit.

2. Separation mechanism

The predicted helicoidal flow determines both the particle separation performance and the solids distribution within a hydrocyclone [9]. There exist two theories on particle separation within a hydrocyclone. The classical Eulerian one, establishes that the flow within a hydrocyclone is a balance between the radial inward drag force and the outward radial centrifugal force. On the other hand, the Lagrangian model or particle tracking theory establishes that the separation mechanism is driven by turbulent radial fluctuations and explicitly enforced force balance. In fact, both theories are complementary.

For dilute systems where the volume occupied by particles may be overlooked. The Eulerian–Lagrangian model can be used

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as proposed by Ma et al. [10]. Other models are proposed by Nowakowski et al. [11], if the concentration of particles exceeds 5% by volume. The particle concentration has an influence on viscosity stresses and, if concentration rises to 10% by volume, the larger particles move towards the less shear strain zone (towards the air-core) and the smaller particles move towards the wall (greater shear strain). In the mentioned study, low solid concentration fields are measured by dual-planar laser-induced fluorescence and the high solids concentration fields by electrical impedance tomography (EIT) [11].

3. Experimental set-up

Two hydrocyclone sizes (5 and 10 cm i.d.) have been used to carry out the experiments described here and to contrast data. They have been designed according to Rietema criterion [12]. Hydrocyclone design parameters following this criterion are calculated based on semi-empirical equations and dimensionless numbers proposed by Svarovsky [13] and Castilho and Medronho [14]. These equations can also help to predict hydrocyclone performance. The geometry of the hydrocyclones used is illustrated in Figs. 1 and 2. Table 1 shows the dimensions of the prototypes used in our study. As it is shown, the inlet pipe is a cylindrical tube, of 9 cm in length for the 5 cm i.d. hydrocyclone and of 18 cm in length for the 10 cm i.d. hydrocyclone that enters tangentially to the cylindrical hydrocyclone body which length is defined as ℓ.

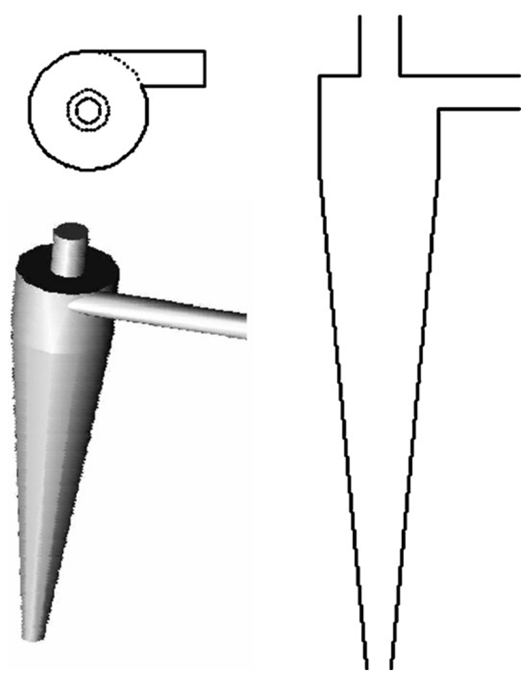

Fig. 1. Some typical views (ground and side) and a schematic 3D diagram of a hydrocyclone.

Table 1
Dimensions (centimetres) of the hydrocyclones used in the experiments

D_C (internal)	D_i	D_o	ℓ	D_u	$L_t - \ell$	θ
5 (m)	1.4	1.7	4	1	21	11.4°
10 (cm)	2.9	3.4	8	2	42	11.4°

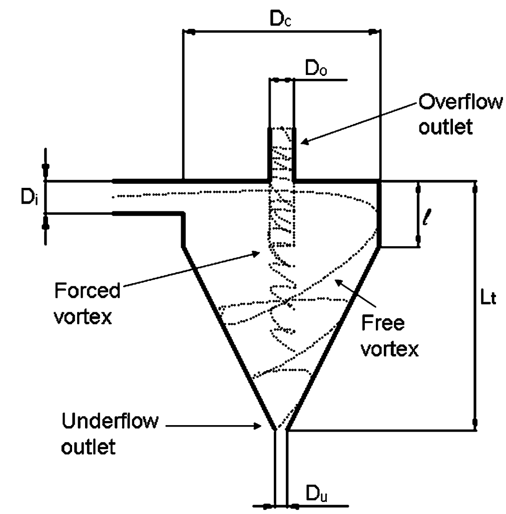

Fig. 2. Schematic diagram of a conventional hydrocyclone.

A scheme of the experimental apparatus is shown in Fig. 3. This consists in a tank provided with a stirrer, which maintains the particles in suspension. The closed-circuit mode of operation means that the discharged underflow and overflow are returned to the feed tank maintaining the concentration at a constant value. Water at room temperature (15 °C) is fed using a 3 kW centrifugal pump P050/30T, passing through a by-pass that regulates the flow, which is controlled by a Khrone Aquaflux 090 K/D DN40 PN 40 electromagnetic flow meter. The hydrocyclones are connected in parallel. The existence of two valves allows operating with a single hydrocyclone in all experiments.

4. Materials and methods

The feed sample was taken directly from the tank. Overflow and underflow samples were taken from the tank return lines. A granulometric analysis was carried out and the suspended solids (SS) concentration was measured for all samples.

The mass of suspended solids is measured after drying a known volume (at 105 °C for a minimum of 6 h) and weighting by difference. The suspended solids tested are composed by $CaCO_3$ with a purity of 81%. According to Perry [15], the value

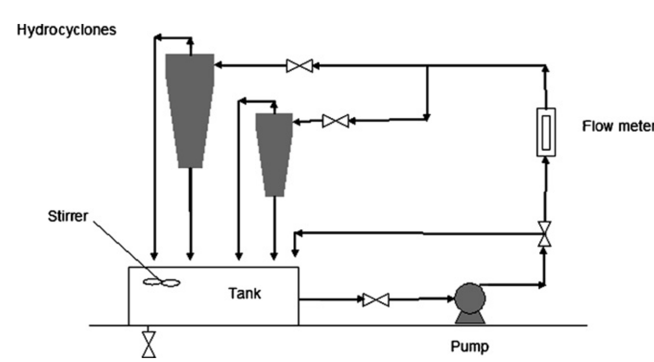

Fig. 3. Simplified flow sheet of the experimental plant.