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Improvements in hydrocyclone design flow lines stabilization

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Abstract

Pressure distribution field within the separation chamber of hydrocyclones is qualitatively and quantitatively analyzed in the context of the design of compact plants for the on-board treatment of ballast water. Once the qualitative analysis has been carried out, the conclusions arising from this analysis have been evaluated by defining a parameter termed "asymmetry coefficient", which provides quantitative information about the behaviour within the hydrocyclone. The influence of the vortex finder both on flow patterns and on air-core precession is successfully studied. As well as giving an insight into hydrocyclone flow lines behaviour, this article attempts to improve operational efficiency by modifying several design parameters in order to provide a stabilization of flow lines (reducing turbulence).

Keywords: Hydrocyclones; Pressure patterns; Flow field; Length increasing; Design; Separation

1. Hydrocyclones as separation unit operations

Hydrocyclones are inertial devices that allow the separation or concentration of macrofluids as suspensions because of the difference between inertial forces that govern the movement of suspended solids in a liquid bulk. Unlike centrifuges, which use the same separation principle, hydrocyclones possess a number of advantages [1–4] such as the absence of moving parts, high capacity, low maintenance requirements, low energy consumption and short residence time.

A hydrocyclone body consists of a chamber integrated by a cylindrical and a conical part as shown in Fig. 1. Hydrocyclone design parameters following Rietema [5] criterion are calculated based on semi-empirical equations and dimensionless numbers proposed by Svarovsky [6] and Castilho and Medronho [7] and Medronho [8].

Therefore, it is important to understand the relative flow pattern and its inherent mechanism that enables separation within the hydrocyclone in order to improve operation performance [9]. The feed slurry enters the hydrocyclone tangentially in the cylindrical upper zone, allowing a progressive separation of the suspended solids from the feed stream. The separation principle is due to the centrifugal forces generated by the tangential motion of the liquid: the circular screw-like trajectory creates a radial acceleration. If the density of solid particles is higher than the fluid density, these particles are impelled to the wall, where they collapse and leave the hydrocyclone through the lower exit, being separated. If the particles are lighter than the liquid phase, these

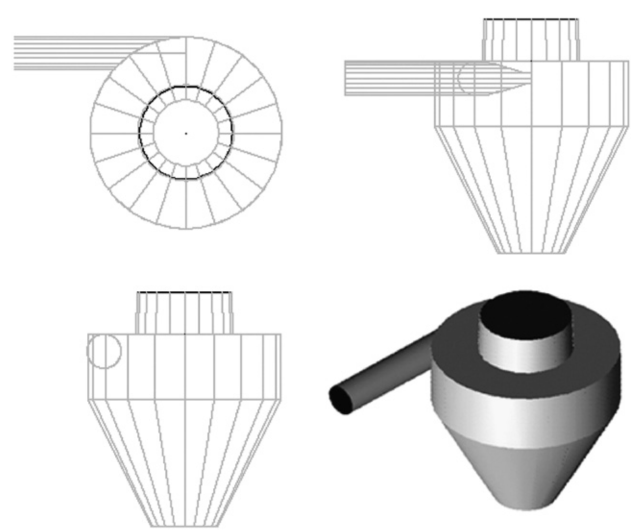

Fig. 1. Some typical views of a hydrocyclone.

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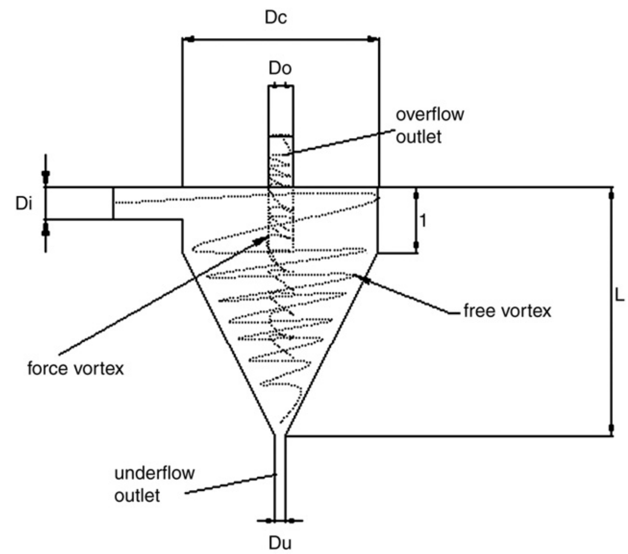

Fig. 2. Schematic diagram of a conventional hydrocyclone.

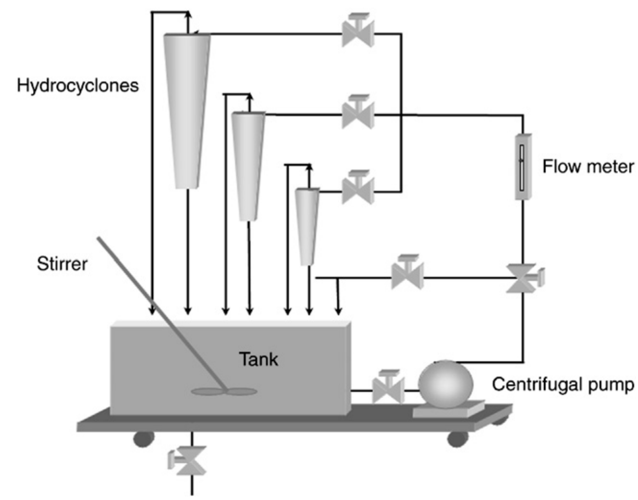

Fig. 3. Simplified flow sheet of the experimental plant.

are differentially carried to the upper exit. The basic flow pattern of a hydrocyclone, the usual nomenclature and some characteristic terms are shown in Fig. 2.

Although the separation principle is well defined and hydrocyclones do not require a complex design, the actual separation mechanism within them is still not well known. Several authors have attempted to model the anisotropic flow [10–18] and complementary research has been carried out related to flow patterns within cyclones [19], providing interesting conclusions in order to understand hydrocyclone behaviour. Prior to these studies, it had been assumed for the purpose of modelling that the flow patterns within a cyclone or hydrocyclone were axisymmetric. This is the proposal of Dyakowski and Williams [20], basing their study on the application of a learning model which takes into consideration mass and momentum principles to predict flow patterns within a hydrocyclone and the regions of high solid concentration. Dwari et al. [3] also consider that turbulent eddy diffusion has a negligible effect on separation. Petty and Parks [21] assumed a non-turbulent flow for hydrocyclones used for oil–water separation.

In this study it is stated by measuring the pressure drop along the axial and radial coordinates of a 18 cm internal diameter hydrocyclone that the flow pattern is asymmetric. Moreover, this paper focuses on how the vortex finder length influences the pressure patterns and air-core precession, with the aim of trying to choose the hydrocyclone configuration with the minimum pressure drop. In order to widen the effect of geometry configuration on pressure patterns, the total cylindrical length on the hydrocyclone has been studied, and its influence has been combined with effects of changing vortex finder length.

Table 1
Dimensions of the hydrocyclone used in the experiment

Parameters	D_i/D_c	D_o/D_c	W/D_c	D_u/D_c	L/D_c	Θ
Rietema	0.28	0.34	0.40	0.2	5	10°–20°
D_c(Internal)						
5 cm	0.28	0.34	0.8	0.2	5	11.4°
10 cm	0.29	0.3	0.8	0.2	5	11.4°
18 cm	0.3	0.33	0.67	0.17	4.17	16.3°
			1.67		5.17	
			3.3		6.83	

2. Experimental set up

Three sizes of hydrocyclone are used to carry out this study, their internal diameters being 5, 10, 18 cm. These have been designed according to Rietema [5] and their dimensions indicated in Fig. 2 are shown in Table 1.

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 measured by a Khrone Aquaflux 090 K/D DN40 PN 40 electromagnetic flow meter. The hydrocyclones are placed in parallel, allowing independent operation. The suspension contained in the tank is continuously stirred to maintain the concentration at a constant value, being conducted through a recirculation system. A flow sheet of the experimental device is shown in Fig. 3.

Results obtained with the 18 cm hydrocyclone, which is provided with fifteen gaps, are described here. With three operating body lengths: 75, 93 and 123 cm, obtained by adding rings to the cylindrical body, the pressure pattern within the hydrocyclone has been determined in the axial and radial coordinates. The vortex finder is introduced inside the hydrocyclone at different heights to prove its effect on separation performance.

3. Materials and methods

The pressure measurements inside the hydrocyclone were carried out using a probe which is introduced within the hydrocyclone and is connected to a U-tube-shaped differential manometer. The pressure drop is measured both in the radial and axial coordinates. In Fig. 4, a schematic diagram of the