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Transition from spray to roping in hydrocyclones

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ABSTRACT

Although roping in hydrocyclones is a problem that has been studied by many researchers, we do not yet have a theory that relates all the variables involved. Several experimental works with different approaches such as mechanical energy balance, work on hydrocyclones with water only and hydrocyclone air core measurements with different instruments in the laboratory and plant have attempted to explain the roping phenomenon. They have addressed design variables such as apex to vortex diameters and different cone angles as well as operating variables such as inlet solid concentration, particle size, pressure and overflow and underflow flow rates and concentrations in order to understand their effect on the roping condition. In this paper we intend to verify some of the conclusions of these studies and establish inlet pressure and particle diameter as the variables that, in combination, lead from spray to roping. We present a computational model using Computational Fluid Dynamics (CFD) to study a 75-mm laboratory hydrocyclone operating at a variable flow rate and with three different particle diameters. The Reynolds Stress Model and Eulerian multiphase model were used to model the turbulence and interaction of phases, respectively. The solid particles are described with the kinetic theory of granular flows (KTGF). Physical coherence and accuracy were compared with experimental data, where errors are within the expected range for an engineering prediction. The results indicate that transition from spray to roping generates an increase in the inlet flow pressure and/or particle diameter at a constant solid concentration in the feed flow. For 20-µm-diameter particles an increase results in a decrease in the discharge angle, although it always has a spray shape, for 34-µm diameters increasing the inlet pressure generates a semi-rope discharge and for 70-µm-diameter particles a small increase in the inlet pressure generates a roping condition. Transition to roping is characterized by a decrease in the air core diameter and discharge angle due to slow rotational velocity when particle diameter increases or higher accumulation of the solid fraction in the apex when inlet pressure increases. The passage from spray to roping occurs with a change in the frequency spectrum of the pressure oscillations in the walls of the hydrocyclone, with high amplitudes at low frequencies for spray discharge and noisy signals in all spectrums and damped low frequencies for roping.

1. Introduction

Although roping in hydrocyclones is a problem that has been studied by many researchers, we do not yet have a theory that relates all the variables involved. Several experimental works with different approaches such as mechanical energy balance, work on hydrocyclones with water only and measurements of air core in hydrocyclones with different instruments in the laboratory and plant have tried to understand the roping phenomena. They have studied design variables such as apex to vortex diameters and different cone angles as well as operating variables such as inlet solid concentration, particle size and pressure and overflow and underflow flow rates and concentrations to understood the effect of them in the roping condition.

Roping in hydrocyclones is a well-known phenomenon in the mining industry and in spite of studies by many researches, theories do not relate all the variables involved and it is still difficult to estimate (Heiskanen, 2000). In this paper we intend to verify some of the conclusions of these studies and establish inlet pressure and particle diameter as the variables that, in combination, lead from spray to roping.

1.1. Experimental information

Bustamante (1991), operating a 6-inch Krebs hydrocyclone and working with water only found that when the pressure is increased until the air core equals the apex diameter, no water leaves through the underflow. He established that the transition from spray to roping in the same hydrocyclone occurs at the same operating conditions as in the case of operating with water. Using the Young Laplace equation,

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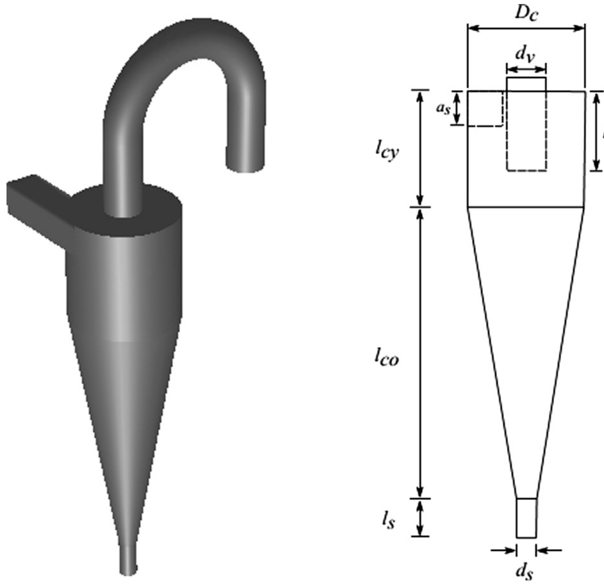

Fig. 1. Hydrocyclone geometry (left) and characteristic dimensions (right).

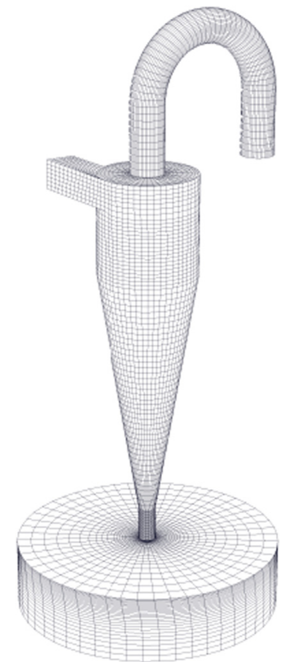

Fig. 2. Grid domain.

Table 1
Geometry and operational conditions.

Parameter	Symbol	Value
Cylinder section diameter	D_c	75 mm
Vortex finder diameter	d_v	25 mm
Spigot diameter	d_a	12.5 mm
Cylindrical section length	l_{cy}	75 mm
Conical section length	l_{co}	186 mm
Vortex finder length	l_v	50 mm
Spigot length	l_s	25 mm
Inlet side length	a_s	22 mm
Particle density	ρ_s	2700 kg/m3
Feed solid concentration	$\rho_{s,inlet}$	26% by volume
Velocity inlet	v_{inlet}	(Case I and II) 2.3, 3.45, 4.6, 5.75 and 6.9 m/s (Case III) 2.3, 3.45 and 4.6 m/s
Inlet pressure associated with inlet velocity	p_i	(Case I) 8.6, 19.2, 33.2, 50.2 and 70.5 psi (Case II) 7.4, 19.1, 25.8, 50.2 and 58.8 psi (Case III) 4.7, 4.8, 8.6 and 14 psi

Table 2
Simulated operating conditions.

Case	Particle size (μm)	Inlet pressure (psi)	Inlet velocity (m/s)
		8.6	2.3
		19.2	3.75
I	20	33.2	4.6
		50.2	5.75
		70.5	6.9
		7.4	2.3
		19.1	3.75
II	34	25.8	4.6
		50.2	5.75
		58.8	6.9
		4.7	1.8
		4.8	2.3
III	70	8.6	3.45
		14	4.6

Concha et al. (1996) indicated that at $d_a/d_v < 0.34$ for this hydrocyclone when working with pulp, roping always exists and for $d_a/d_v > 0.50$ there is no roping for any operating conditions. In the intermediate range, $0.34 < d_a/d_v < 0.50$, spray and roping can coexist depending on other variables such as pressure, feed concentration, particle feed size and size distribution. Using this approach it was possible to predict spray or rope discharge for all cases presented by Plitt et al. (1987), and Concha et al. (1996) proposed an equation for the air core diameter for this case. Castro et al. (1996) developed an equation for the air core in terms of the apex-to-vortex ratio, inlet pressure and pulp viscosity from data obtained in an industrial hydrocyclone at the Chuquicamata copper concentrator.

Williams et al. (1999), using Electrical Resistance Tomography, measured the air core in a 50-mm hydrocyclone. They observed that the air core increased from 4.0 to 4.4 mm as the pressure increased from 1 to 3 bars. Neesse et al. (2004a) studied the formation of the air core, the shape of the underflow discharge and the sediment mass stored in the hydrocyclone. In their words, the transition between spray and rope can be described as follows:

(a) *In dilute flow separation, with its typical spray discharge, a throughgoing air core can be observed that extends to the underflow. The separation presents high solids recoveries as an advantage but low solids concentrations resulting in more fines being swept into the underflow.*
(b) *The transition state between spray and rope is an unstable state with rapid changes between these two discharge types. Because of the remarkable separation effects in the transition phase the monitoring of this state is of special interest.*
(c) *In dense flow separation, more solids are stored in the conical part of the hydrocyclone and partly forced to the overflow, consequently reducing solids recovery to the underflow. The air core is not going through and oscillates intensively. The discharge assumes the shape of a rope and is characterized by high solids content and less fines, which is the advantage of this variant.*

To detect the onset of roping they used several instruments: a laser beam for detecting the shape of the discharge, a capacitance sensor for the on-off detection of spray-roping, a gravimetric instrument to weigh the solid material accumulating inside the hydrocyclone and an acoustic sensor to detect hydrocyclone wall oscillations. In the range of low frequencies < 100 Hz, spray discharge presents a higher oscillation intensity for roping then for spray discharge, while for the high