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Numerical analysis of hydrocyclones with different vortex finder configurations

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ABSTRACT

This paper presents a numerical study of the multiphase flow and performance of hydrocyclone by means of two-fluid model, with special reference to the effects of diameter, length and shape of vortex finder at a wide range of feed solids concentrations. The considered shapes include the conventional cylindrical style and the new conical and inverse conical styles. The simulation results are analysed with respect to cyclone flow and performance in term of cut size d_{50}, water split, Ecart probable E_p and inlet pressure drop. It is shown that when vortex finder diameter or shape varies, a compromised optimum performance can be identified, resulting in relatively small inlet pressure drop, E_p, and water split. Both d_{50} and E_p are more sensitive to feed solids concentration than inlet pressure drop and water split. Overall, the effect of vortex finder length on the separation efficiency of particles is much less significant than diameter and shape, which shows opposite trends at low and high feed solids concentrations. All these results can be well explained using the predicted tangential and axial velocities and solid volume fraction.

1. Introduction

Hydrocyclones are widely used to separate particles by size in many industries such as chemical, mineral, coal preparation, and powder processing industries. Some advantages associated with such a separator include design simplicity, high capacity, low maintenance and operational costs. On the other hand, the disadvantages of the cyclone include high energy loss and unsatisfactory separation efficiencies such as misplaced particles at both the overflow and underflow, and limitations on separation performance in terms of the sharpness of the cut and the range of operating cut size (Svarovsky, 1984). To date, finding applicable solution to overcome these deficiencies is still a challenge, particularly at different feed solids concentrations.

The internal space within a hydrocyclone can be largely divided into three parts: the pre-separation space between the vortex finder and the column wall, the main separation space below the vortex finder, and the space occupied by the air core. It is known that by properly changing the dimension and shape of vortex finder, the flow in the pre-separation space can be controlled to improve cyclone performance such as energy utilization and particle separation efficiency. In the past decades, various experimental and numerical studies have been made in this direction. The vast majority of such studies focused on the optimum dimension of vortex finder with respect to length, diameter and wall thickness (Kelsall, 1953; Xu et al., 1991; Olson and Van Ommen, 2004; Martinez et al., 2007, 2008; Wang and Yu, 2008; Motsamai, 2010; Kilavuz and Gulsoy, 2011; Yang et al., 2011; Murthy and Bhaskar, 2012). Some design modifications on shape of vortex finder have also been made continuously (Kelsall, 1952; Duijn and Rietema, 1983; Arato, 1984; Rajamani, 1987; Chu and Luo, 1994; Wang and Yu, 2008; Silva et al., 2012). However, the previous vortex finder shapes were considered at specific dimensions. Their geometrical configurations are generally complex, which are not desirable for equipment manufacture and wear prevention. Another deficiency associated with the previous studies is that the effect of vortex finder was often investigated at relatively low feed solids concentrations. However, hydrocyclones are often operated at different feed solids concentrations in practice and show different performance (Slechta and Firth, 1984; Dyakowski and Williams, 1996; O'Brien et al., 2000; Hararah et al., 2010; Zhang et al., 2011). To date, a comprehensive study of vortex finder configuration at different feed solids concentrations has not been found in the literature.

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Nomenclature

C_d	fluid drag coefficient
d	particle size, m
$D_{T,ij}$	Turbulent diffusion term
e_{kk}	restitution coefficient between particles
E	Young's modulus, Pa
f_{drag}	fluid drag force, N
g	gravity acceleration vector, 9.81 m/s^2
p	pressure drop, pa
P_{ij}	Stress production term
u	fluid velocity, m/s
x_i	Cartesian coordinate
R_f	amount of water split to underflow
r	radial distance, m
Re	Reynolds number

Greek letters

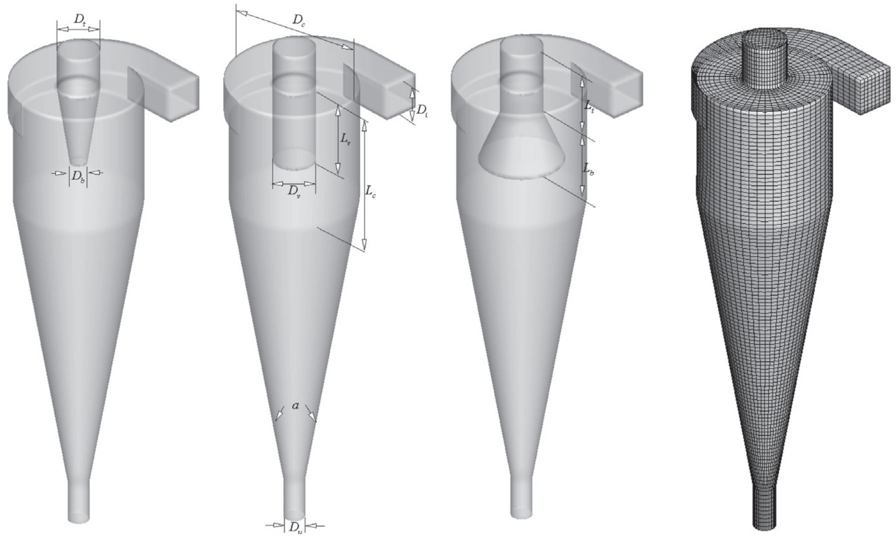
α	volume fraction
ϕ_{ij}	pressure strain term
ε_{ij}	dissipation term
σ_t	Prandtl–Schmidt number
ρ	fluid density, kg/m^3
τ	particle relaxation time
η_t	turbulent diffusivity
$\gamma\Theta$	collisional dissipation of energy, J
ϕ_l,k	energy exchange between the lth solid phase and the kth solid phase, J
Θ	granular temperature, m^2/s^2
μ	fluid viscosity, kg/m/s

Subscripts

c	corrected
col	collision
cut	cut size
dr	drift velocity
k	phase k
kin	kinetic
l	phase l
m	mixture

Computer modelling and simulation can provide an insight into a hydrocyclone about the complicated inner multiphase flows which govern the equipment performance but are difficult to measure, especially for opaque slurry and/or at a relatively high feed solids concentration. It has been widely used to study hydrocyclones in recent years (see, for example, the reviews by Nowakowski et al., 2004; Narasimha et al., 2007). Generally speaking, the numerical models used can be classified into two groups: CFD-LPT (Computational Fluid Dynamics-Lagrangian Particle Tracking) and TFM (Two-Fluid Model). The previous numerical studies of vortex finder were mainly based on the CFD-LPT approach (Olson and Van Ommen, 2004; Wang and Yu, 2008; Motsamai, 2010; Murthy and Bhaskar, 2012). However, such an approach traces only the motion of a single particle, and ignores the effect of inter-particle interactions and the reaction of particles on the fluid. Therefore, it is largely limited to hydrocyclones operated at a low feed solids concentration or in a dilute flow regime. Conversely, in the TFM approach, both the fluid and solid phases are treated as interpenetrating continuum media, considering the interactions between particles and between particles and fluid. It can, to a large extent, overcome the problems associated with the CFD-LPT approach. Therefore, the TFM approach has been increasingly used to study hydrocyclones in both dense and/or dilute regimes by different investigators (Nowakowski et al., 2000; Huang, 2005; Brennan et al., 2007; Noroozi and Hashemabadi, 2009; Kuang et al., 2012; Narasimha et al., 2012; Swain and Mohanty, 2013). However, while confirming the capability of TFM approach, the previous TFM studies were rarely used to investigate the effects of geometrical variables on hydrocyclone flow and performance.

In this study, the flow in hydrocyclones is studied by means of the TFM model recently developed by Kuang et al. (2012). The emphasis is given to the influences of the diameter, length and shape of vortex finder on the flow and performance at different feed solids concentrations. This is different from the previous study that focused on model development and validation for a given geometry (Kuang et al., 2012). The vortex finders of the hydrocyclones considered here include the conventional cylindrical style and the new conical and inverse conical styles, as illustrated in



D_d/D_t=0.4 (cone) 1 (cylinder) 1.6 (inverse cone) 1

Fig. 1. Vortex finder of different shapes simulated and mesh for the base case.