Powder Technology 305 (2017) 156–165

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Effects of curvature radius on separation behaviors of the hydrocyclone with a tangent-circle inlet

Caie Zhang, Dezhou Wei *, Baoyu Cui, Tianshu Li, Na Luo

School of Resources & Civil Engineering, Northeastern University, Shenyang 110819, China

A R T I C L E   I N F O

Article history:
Received 10 July 2016
Received in revised form 18 September 2016
Accepted 3 October 2016
Available online 03 October 2016

Keywords:
Hydrocyclone
Tangent-circle inlet
Curvature radius
Computational fluid dynamics (CFD)
Flow field
Pressure drop

A B S T R A C T

An appropriate design of the inlet type has been proved to be an effective approach to improve the performance of a hydrocyclone. Until now, there is still no detail analysis on the mechanism underlying the flow control by the inlet type. In this paper, numerical simulation was conducted to investigate effects of curvature radius on the separation performance of the hydrocyclone with a tangent-circle inlet. The validity of the approach was verified by the reasonably good agreement between the predicted and measured results in terms of water velocities and particle partition curves. The simulating results were further analyzed in aspects of the flow field, pressure drop and separation performance. Results showed that a smaller curvature radius could increase the tangential velocity and the pressure gradient. Besides, the turbulence kinetic energy in the inlet section and the annular section are reduced by decreasing the curvature radius. Meanwhile, the symmetry of the inner flow field was improved by reducing the curvature radius. All these factors enhanced the radial regular distribution of particles in the inlet section and reduced influences of the short circuit flow on relatively coarse particles. Therefore, the classification precision was improved when using a tangent-circle inlet with a smaller curvature radius compared with base hydrocyclone.

1. Introduction

Hydrocyclones are widely used in the mineral processing industry for the solid-solid separation by particle size differences, due to their design simplicity, flexibility of operation and low operation costs [1,2]. The feed flow with a certain pressure enters into the hydrocyclone through the inlet, and then is divided into the underflow and the overflow. During the separation process, the inlet can guide and accelerate the feed flow [3]. Therefore, the inner field and the performance of a hydrocyclone can be controlled by the inlet. High separation precision with no misplaced particles is considered as the ideal separation results of the hydrocyclone [4]. However, the traditional hydrocyclones with a single linear type inlet often give a poor separation performance because of its unstable inner flow field and high turbulence intensity [5]. Thus, numerous studies have been conducted to overcome these problems with different inlet configurations [6,7].

It is believed that a reasonable design of the inlet type may be beneficial to the inner flow field, and facilitate the performance of a hydrocyclone [2,4]. Several inlet types such as the involute inlet, spiral inlet, arcs inlet and tangent-circle inlet has been reported and applied to obtain high separation precision [8–10]. All the above inlets can be considered as a combination of multi-section tangent-circle inlets with different curvature radius. Furthermore, previous studies show that the tangent-circle inlet cyclone is highly effective in improving the stability of the inner flow field and reducing the amount of misplaced particles, thereby a better separation performance can be obtained compared with other inlet types [11]. In addition, it is easy to be manufactured, making it have practical importance in industrial application. Generally, the separation performance of hydrocyclone is mainly determined by geometric and operational parameters [12,13]. Therefore, some explicit approaches have been conducted in the past to optimize the performance by adjusting those parameters of the tangent-circle inlet cyclone. For example, by means of adjusting geometric parameters such as inlet size, cylindrical length, conical length, vortex finder length and diameter, spigot diameter and so on, relative small values of the inlet pressure drop, the Ep and the water split were observed [14–17]. Furthermore, the modifications on the traditional hydrocyclone by a convex cone or an inverse conical style vortex finder are proposed to improve the performance of cyclones [16,18]. In respect of optimizing operation parameters, relative researches are focused on the feed solid concentration, fluctuations of the feed and vortex finder outlet pressure. Decreasing the feed solid concentration and reducing the vortex finder outlet pressure can promote the separation precision, while the fluctuation only affects the separation efficiency slightly [19–21]. However, the effects of the curvature radius on the fluid flow and the particle separation in the hydrocyclones with a tangent-circle inlet are not mentioned so far in relevant studies. Thus, a detail analysis with respect to the curvature radius will fetch a better understanding

* Corresponding author at: No. 3-11, Wenhua Road, Heping District, Shenyang 110819, China.
E-mail address: dzwei@mail.neu.edu.cn (D. Wei).

http://dx.doi.org/10.1016/j.powtec.2016.10.002
0032-5910/

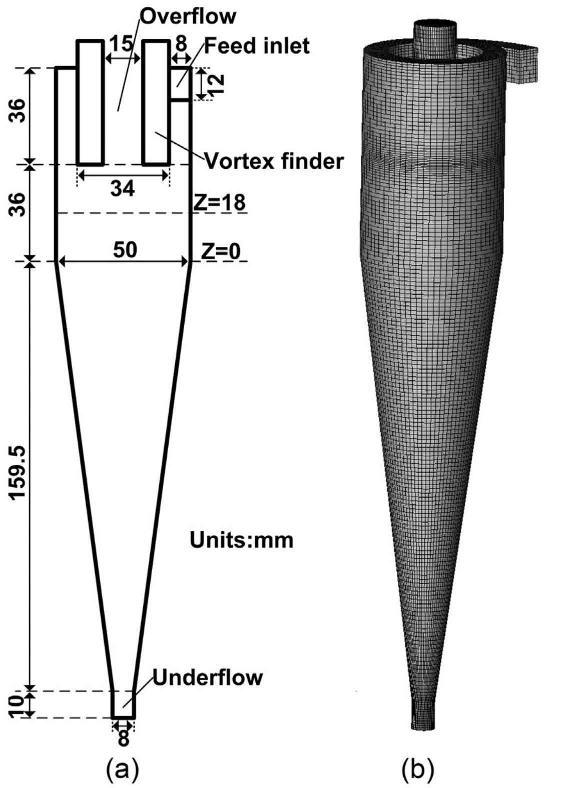

Fig. 1. Geometrical parameters (a) and domain mesh (b) of the hydrocyclone.

of the separation properties and lay a foundation for the design of a new type inlet.

The flow in a hydrocyclone is quite complex. This complexity is basically caused by the existence of swirling turbulence flow, particles with different size and the air core [22]. Therefore, the computational fluid dynamics (CFD) technique was applied to generate some insights into a hydrocyclone regarding the complicated multiphase flows and solid distributions. In recent years, it has been proved as an efficient method to study hydrocyclones. Generally speaking, the used models can be divided into a turbulence model and a multiphase model. Both the Reynolds stress model (RSM) and the large eddy simulation (LES) can give good predictions of velocities, as reviewed by Narasimha [23]. However, the LES model is computationally impractical due to the finer grid requirements and the shorter time steps. In addition, the volume of fluid (VOF) model has a sufficient accuracy in describing the free interface between the air core and the liquid when compared with results of the PIV experimental measurement [24]. For the prediction of the solid flow, the numerical models were mainly based on the CFD-LPT and the mixture model [21]. CFD-LPT is only applicable to simulate hydrocyclones processing the feed with a low solid concentration. Mixture model which can be regarded as a simplified two fluid model (TFM) has been proved to be valid for hydrocyclones with a high feed solid concentration [25].

In this paper, the effects of curvature radius on the flow and performance of the hydrocyclone with a tangent-circle inlet are computationally investigated. The application of the model is firstly examined by comparing the measured and calculated results in terms of water velocities and particle partition curves. The flow features are further examined in terms of the flow field, the pressure drop, and the separation performance. These findings can be beneficial not only for establishing a comprehensive picture about the effects of the curvature radius but also for designing a new inlet type.

2. Mathematical model

2.1. Model description

The modeling of the complex flow in a hydrocyclone is divided into two steps. Firstly, the air and water are considered as fluids with a homogeneous viscosity. The turbulence is modeled using the Reynolds stress model (RSM) and the air-liquid interface is captured by the volume of fluid (VOF) model. The flow field characteristics are obtained.

Secondly, the solid particles are added to estimate the separation performance. The results obtained from the first step are used as parts of the initial conditions. The mixture model is used to describe the flows of solid particles and the air. In this model, the bubble size is set to 1×10^{-5} mm, as reported by Kuang [26], in order to calculate the drift velocity between the water and air. Besides, the properties of the solid particles are given by the kinetic theory. Details of the models used in this research have been well documented in literatures [21,27].

2.2. Simulation conditions

Six hydrocyclones with different curvature radius are considered here. And the results are compared with those obtained from the base hydrocyclone which has a single linear type inlet. In each situation, only the curvature radius is set as a variable while other parameters

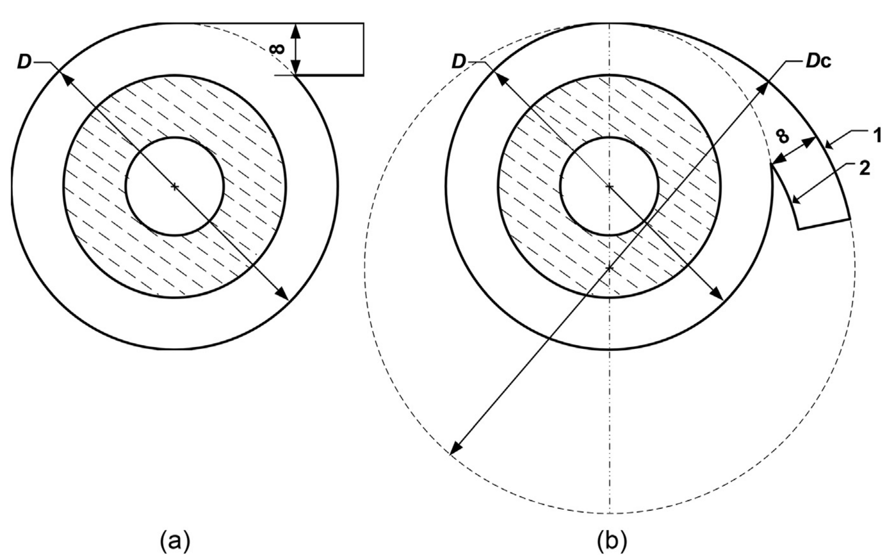

Fig. 2. Structure of the linear type inlet (a) and the tangent-circle inlet (b).