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Original Research Paper

Performance evaluation of a hydrocyclone with a spiral rib for separation of particles

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ABSTRACT

Several design modifications have been done to improve particle separation efficiency in a hydrocyclone. The effects of a rib which is introduced into the cylindrical part of the hydrocyclone are discussed here. CFD (Computational fluid dynamics) is a useful tool to study the velocity and pressure distribution of complex turbulent flow in a hydrocyclone. Flow simulations are carried out using a three-dimensional double precision, segregated, steady-state solver tool. Reynolds stress model is employed for turbulent model which is suitable for the anisotropic turbulent flow. A comparison study for pressure drop and flow velocity for the conventional and ribbed hydrocyclone have done. The obtained CFD simulated results in correlation with experimental data shows that the pressure drop reduces by 13.9% at a velocity of 2.5 m/s by using rib. An experimental finding shows that the cut size particle diameter for conventional and ribbed hydrocyclone are 36 μm and 28 μm respectively at the velocity of 2.5 m/s.

1. Introduction

Hydrocyclones are one of the most widely used classifiers based on particle size, shape and density whose advantages include large capacity, small volume, no moving parts, faster separation process, operational reliability and economic feasibility. These are the devices most frequently used for the separation of particles in a mixture of liquids having different size, shape and density. A conventional hydrocyclone consists of feed inlet, cylindrical and conical section, a vortex finder, and an apex. It is also an efficient separator for separating fine and coarse particles, widely used in mineral processing [1,2], petrochemical engineering [3–5], food engineering [6,7], pulping [8], electrochemical engineering [9], waste water and effluent treatment [10,11] and other industries handling with slurries. Feed is injected tangentially which creates centrifugal force inside the hydrocyclone. The device converts the linear motion of the fluid into varying angular motion, which enhances the rate of settling of particles due to centrifugal acceleration. Although the geometrical structure of a hydrocyclone is simple, but the multiphase flow behavior of the hydrocyclone is complex in nature.

The hydrocyclone operation is simple, but the complex flow pattern due to turbulent flow, formation and breakdown of vortices, flow inversion, air core formation of the three phases inside the hydrocyclone has been a matter of interest in the academia by experimental as well as the numerical methods [12–14]. The flow pattern inside the hydrocyclone depends on the operational and geometrical parameters of the device that determines the performance [15–22]. The operational conditions such as feed solid concentration, solid particle size, and feed flow rate are different for various applications. Enormous works of experimental, theoretical and numerical investigation have been carried out on different types of hydrocyclones. Water purifier later named as hydrocyclone was first patented by Bretney [23]. In a hydrocyclone lighter particles flow toward the inner spiral and collected from the overflow and the coarse or heavy particles move toward the wall of the hydrocyclone separator through the outer spiral and collected from the underflow. The sharpness of separation is not high under the best circumstance because particles from the inner spiral flow toward the wall of the hydrocyclone and some coarse particles directly discharge through the over flow. So some modifications have been made to improve performance of hydrocyclone for solid separation. Chu and Luo attached vortex finder with the hydrocyclone for the better performance [24]. The sharpness of separation

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Nomenclature

D_C	hydrocyclone diameter (cm)	θ	included cone angle of the hydrocyclone (–)
L_1	height of cylindrical section (cm)	η	separation efficiency (–)
L_2	height of conical section (cm)	STD	standard deviation (–)
D_U	diameter of apex (cm)	U_{max}	maximum uncertainty (–)
D_O	vortex finder diameter (cm)	U_{min}	minimum uncertainty (–)
l	vortex finder length (cm)	VOF	Volume of Fluid (–)
Δp	pressure drop (kPa)		
ρ	fluid density (kg/m^3)		

with attached vortex finder and a central cone is more than that of the conventional one. Different types of conical section is designed to enhance the performance [25,26]. Two inlet hydrocyclone was introduced by Nenu and Yoshida [27]. A three product hydrocyclone was developed which generates two underflows and one overflow [28]. In some modifications, an axial cylindrical rod was introduced at the central axis of the hydrocyclone to remove the central air core [14,29]. The turbulence inside the hydrocyclone affects the performance of the hydrocyclone [30].

Computational fluid dynamics has a great potential to study the flow field behavior, pressure drop and particle trajectories inside the hydrocyclone [15,18,31–33]. As the flow pattern inside the hydrocyclone is complex, numerical simulation unable to substitute experiments completely but can reduce the experimental costs for design and optimization to a certain extent. Extensive work has been done on performance, scale-up, modeling and simulation of hydrocyclones. But, there is limited information available on effect of ribs for the separation performance and flow behavior of hydrocyclone. Farahani et al. [34] designed a cyclone with internal spiral ribs and analyzed the effects of ribs on flow pattern and predicted performance using CFD techniques. The main objective of this study is to analyze the influence of a rib (a rib is nothing but a rectangular strip which is swept along a helical path) in a hydrocyclone by experimentation and CFD simulations. The effect of rib on the pressure drop, tangential and axial velocity, and performance efficiency for a Newtonian fluid is analyzed. In this work, the hydrocyclone is modified by inserting a spiral rib inside the hydrocyclone and the experiments are conducted at different inlet velocities. The effects of inlet velocity on the pressure drop and particle separation efficiency are analyzed and reported. The experimental results of the pressure drop and the separation efficiency of the modified hydrocyclone are compared with the hydrocyclone without rib. The complex flow behavior inside the hydrocyclone is investigated using CFD technique. CFD code is used based on the Reynolds Averaged Navier-Stokes approach. Three-dimensional turbulent flow equations are numerically solved. The effect of rib on flow field and performance of the hydrocyclone are also investigated using the Fluent commercial software.

2. Experimental

2.1. Materials

The material used for this investigation is sand. The density of the sand particle is 2500 kg/m^3. Sand particles are ground and screened to different particle size range 1 μm to 300 μm sand particles are utilized for the experiment. Sand–water slurry of 1 vol% is prepared and stored in the storage tank for the experiment.

2.2. Experimental procedure

The schematic diagram of the experiment setup is shown in Fig. 1(a) and the schematic diagram focused on ribbed hydrocyclone is shown in Fig. 1(b). The setup consists of a hydrocyclone, supply tank, centrifugal pump, and a rotameter. The hydrocyclone is made up of transparent Perspex material, and the dimension is given in Table 1. The top of the cylindrical part is closed by a flat head, and a concentric pipe known as vortex finder is protrudes some distance into the hydrocyclone body. The feed slurry is injected tangentially by an inlet rectangular pipe that is fitted tangentially to the cylindrical part of the hydrocyclone. A large tank of capacity 500 l is used for both storages as well as for collecting overflow and the underflow discharge. The centrifugal pump injected the slurry at a very high velocity to the hydrocyclone. The feed slurry velocity ranges from 1 to 2.5 m/s for the experimental study. At low inlet pressure around 1 kPa, proper vortex did not form. After increasing the flow rate, when flow attained the steady state, slurry samples are collected from the inlet, overflow and the apex. The overflow is collected through the vortex finder. The coarser particles are collected from the apex of the hydrocyclone. The pressure drop is measured by using mercury manometer. Inlet flow pressure is measured to find out the pressure drop across the hydrocyclone. Samples are collected for the particle size analysis by varying the flow velocity. The inlet velocity is considered as variable to study the pressure drop and performance of the hydrocyclone. All the experiments are performed by changing the flow velocity. Feed sample is collected from the bypass. Overflow and underflow samples are collected from the respective streams. Part of the wet samples are taken for particle size analysis by Malvern particle analyzer. Some samples collected are weighted, filtered and then dried to calculate the weight% of solid content. By knowing the particle weight% and particle size from three streams, the efficiency of separation by hydrocyclone can be calculated. The efficiency of hydrocyclone is defined as the percentage of feed material of a given size which reports to the underflow stream.

2.3. Design modification

In the present study, a hydrocyclone with internal spiral ribs have been studied. The experimental setup of the ribbed hydrocyclone is shown in Fig. 2. A Spiral rib has been designed and fabricated of stainless steel and inserted in the cylindrical portion of the hydrocyclone. The spiral rib is fixed to the wall of the hydrocyclone with a thin joint in such a way that the flow field inside the hydrocyclone affect is minimum. Width and thickness of the strip are 0.8 cm and 0.2 cm respectively. Spiral rib used for the experiment is shown in Fig. 3. Similar procedures as mentioned above are repeated by inserting the helical ribs inside the hydrocyclone.

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