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Role of vortex finder depth on pressure drop and performance efficiency in a ribbed hydrocyclone

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A B S T R A C T

Hydrocyclones are devices used in many chemical and mineral based process industries for separation of fine particles. To enhance the performance efficiency of hydrocyclone with optimum pressure drop several configuration of hydrocyclone is designed and developed. A new hydrocyclone with spiral rib was designed. In the present study, the effects of spiral rib on pressure drop and separation efficiency are investigated experimentally and effect of vortex finder depth of a ribbed hydrocyclone was analyzed. The experimental results showed that the spiral rib has a significant effect on pressure drop and separation efficiency. It is interesting to note that by using a rib in the cylindrical part of the hydrocyclone resulted in lower pressure drop and improved separation efficiency. The pressure drop decreases by 17.5% and total efficiency increases by 10.5% at a feed velocity of 5 m/s and at a vortex finder depth of 7.6 cm. Pressure drop and separation efficiency also affected by the vortex finder depth. In this study, four ribbed hydrocyclones with 6 cm, 7.6 cm, 9.8 cm and 12.5 cm vortex finder depth have been taken for the analysis. Separation efficiency is maximum for the vortex finder depth of 7.6 cm.

1. Introduction

Hydrocyclones are widely used in mineral and allied process industries because of its advantages such as easy to install, no moving parts, high separation efficiency, operational reliability and economically viable. It is also used in food process industry (Trim and Marder, 1995; Dickey et al., 1997), pharmaceuticals (Ozgen et al., 2009; Boylu et al., 2010), waste water and effluent treatment (Klima and Kim, 1998; Zhumabekov et al., 2014), mineral processing (Maharaj et al., 2011) and other industries handling with slurries. Operation of a hydrocyclone is simple, but the flow behavior inside the hydrocyclone is very complex in nature. Hydrocyclone was used as water purifier and first patented by Bretney (1891). Enormous works of experimental, theoretical and numerical investigation have been carried out on different types of hydrocyclones in the recent past. Duijn and Rietema (1983) introduced large cone angle hydrocyclone and reported the performance. Dwari et al. (2004) designed a hydrocyclone that can operate for sand, FCC catalyst and fly ash. Neesse and Dueck (2007) demonstrated that the air core radius can be calculated by knowing the geometry of the hydrocyclone. It has been reported in the literature that several attempts have been made to improve the performance of hydrocyclone by modification. Nenu and Yoshida (2009) have been carried out a number of experiments to investigate the particle separation performance of a single and two inlet hydrocyclones. Filtering hydrocyclone is a hydrocyclone whose conical section is replaced by a conical filtering wall and the performance of a filtering hydrocyclone is better than that of a conventional one under the same geometry and operating conditions (Vieira et al. 2007, 2010; Vieira and Barrozo, 2014; Silva et al., 2015). A solid rod is introduced to prevent the formation of air core in the hydrocyclone (Lee and Williams, 1993; Chu et al., 2004; Sripriya et al., 2007). Zhang et al. (2013) modified the conventional tangential inlet hydrocyclone with an Archimedes spiral inlet hydrocyclone. An impeller was installed around the vortex finder by Rajamani (2007) to improve the classification efficiency of a hydrocyclone. A three outlet hydrocyclone that generates one overflow and two underflows was developed by Ahmed et al., (2009). Zhao et al. (2012) developed an inner core hydrocyclone, which is highly efficient and also more stable. Hydrocyclone classification of particles in the micron range was developed by Endres et al. (2012). A high pressure hydrocyclone for solids classification

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in the submicron range was developed by Neesse et al. (2015).

The vortex finder depth was considered as a design parameter because many authors have reported that the vortex finder could affect the separation efficiency. Chu and Luo (1994) attached vortex finder with the hydrocyclone. Hwang and chou (2017) developed a hydrocyclone by changing the vortex finder structure for high separation efficiency of the hydrocyclone. The vortex finder is designed with some annular teeth which guides the particles and liquids and avoids short circuit flow. Ficici et al. (2010) investigated the effect of vortex finder dimension on the pressure drop in cyclone separators. Lim et al. (2004) evaluated the performance of a cyclone with different vortex finder shapes. Wang and Yu (2008) numerically study the flow behavior of different shaped vortex finder. Ghodrat et al. (2014) numerically study the multiphase flow behavior and performance of a hydrocyclone by varying the solid feed concentration giving special reference to the effect of length, diameter, and shape of vortex finder.

Many modifications have been done to improve the performance, but little information is available on the effect of ribs on the separation performance and flow behavior of hydrocyclone. Noode Farahani et al., (2011) designed a cyclone with ribs and analyzed the effects of ribs on flow pattern and performance. The collection efficiency increases with the presence of the ribs. The main objective of this study is to improve separation efficiency and to reduce the pressure drop by introducing a spiral rib by experimental investigation. Therefore in this work an attempt have been made to design and characterize a hydrocyclone with internal ribs. Spiral rib was fabricated in the laboratory at Indian Institute of Technology, Kharagpur and inserted inside the hydrocyclone. During experimentation, inlet flow velocity and vortex finder depth were considered as the variables. The effect of these variables on pressure drop and separation performance was also analyzed.

2. Materials and methods

2.1. Materials and experimental procedure

The schematic diagram of the experiment setup is shown in Fig. 1. The experimental set-up mainly consists of a hydrocyclone, supply tank, centrifugal pump and rotameter. A hydrocyclone according to the geometric characteristics of Rietema hydrocyclone was designed and a spiral rib was introduced in the cylindrical part of the hydrocyclone. The hydrocyclone was made up of Perspex material having diameter 15.2 cm, length of the cylindrical part 22.7 cm and a conical section of 38.1 cm. The dimension of the hydrocyclone used for the present study is given in Table 1. The top of the cylindrical part was closed by a flat head through which a vortex finder pipe was inserted to a certain depth into the cylindrical part that avoids the short circuit flow. At the bottom, the apex pipe was attached through which coarse or heavier particles were separated out. Appropriate modification has been done for the ribbed hydrocyclone to enhance their performance characteristics. A 0.5 horse power (H.P) centrifugal pump was used to pump the slurry in to the hydrocyclone. A gate valve was fitted between the slurry tank and the centrifugal pump to maintain the volumetric flow rate. The volumetric flow rate can be measured by using the rotameter mounted along with the delivery pipe. Manometers were inserted in the inlet and outlet to measure the pressure drop of the hydrocyclone. The feed slurry was injected tangentially into the inlet section of the device. The pressure drop was measured by a mercury manometer. A 0.5 m^3 capacity tank was used for collection of recycled liquid from overflow and underflow and again recycled back to the inlet section of hydrocyclone. The slurry concentration in the slurry tank was maintained a constant value as the flow from underflow, overflows, was recycled back to the tank.

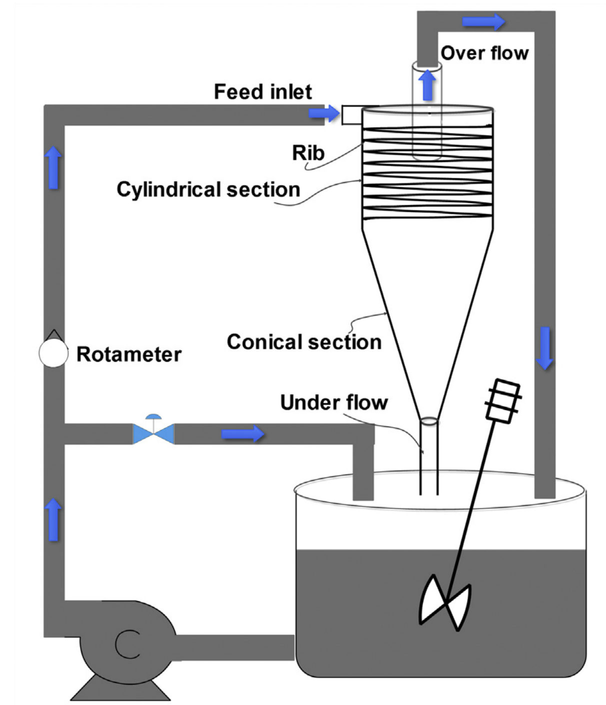

Fig. 1. Schematic diagram of the experimental setup.

Table 1
Dimensions of the hydrocyclone used for experiment.

Sl. No	Parameter	Dimensions (cm)
1	Diameter of hydrocyclone (D_C)	15.24
2	Height of cylindrical section	22.78
3	Height of conical section	38.1
4	Diameter of vortex finder (D_O)	5.08
5	Diameter of apex (D_U)	2.54
6	Feed inlet	5.08 × 2.54
7	Included angle (θ)	18°

Separation occurs inside a hydrocyclone due to the swirling motion of the fluid and the suspended particles. The feed was injected tangentially to produce centrifugal force field. The flow inside the device was three dimensional and highly turbulent. The heavier or coarse particles move towards the wall of the cone and were collected from the apex pipe. Very high angular momentum inside the hydrocyclone creates an area for low pressure along the central axis.

Separation of particles in a hydrocyclone is based on size, shape and density of particles as far as solid material is concerned. Preparation of slurry for the experimental purpose is a significant part of this work. Sand particles having density 2500 kg/m^3 was used for the experimental performance study of the hydrocyclone. Experiments were first conducted with water only and then with slurry. The former gave insight about the basic properties of hydrocyclone like flow split, etc. The centrifugal pump injects the feed slurry in to the hydrocyclone at a very high velocity. The feed slurry velocity ranges from 1 to 5 m/s. The experimental conditions were maintained during the study are shown in Table 2. Slurry samples at the inlet, over-flow and under-flow were collected when flow attained the steady state. Inlet flow pressure was measured by using manometer to find out the pressure drop across the hydrocyclone. To study the pressure drop and separation efficiency of the hydrocyclone; inlet velocity, and vortex finder depth were