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Improvement of the filtration characteristics of calcite slurry by hydrocyclone classification

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ABSTRACT

Hydrocyclones are used in the classification of solids for instance in the mining and minerals processing industries for modifying the particle size distribution of solids, as well as for ore concentration purposes. Improvement in the filtration properties of the slurry is usually achieved as a result of the classification process when only the underflow is evaluated, owing to the coarse and narrow particle size distribution. However, overall comparisons of the filtration properties incorporating filtration of both the underflow and overflow streams have not been discussed a lot in the literature. The objective of this study is to investigate hydrocyclone classification of a calcite slurry, to evaluate the resulting pressure filtration properties of the underflow and overflow streams, and to compare the required total filtration areas for a constant solids production capacity. The results show that the average specific cake resistance depended primarily on the fine particle content of the slurry, and therefore the Kozeny-Carman equation was not suitable for the prediction of the specific cake resistance. The specific resistances of feed and underflow filter cakes were underestimated consistently. Wide particle size distribution was one of the most apparent factors reducing cake porosity. The main outcome of the comparison of the required filtration areas was that a low specific cake resistance and high solids concentration of the underflow caused the total area requirement to decrease almost in all cases, compared to the area required for the filtration of the feed slurry. Moreover, as high as 99% reduction in the total filtration area, compared to the feed slurry, could be achieved by filtering only the underflow streams, omitting the dewatering of the overflow streams. In the light of the promising results of the study, the incorporation of a classification step prior to filtration should be investigated further, e.g. in tailings treatment applications.

1. Introduction

Hydrocyclones are used for various classification purposes in the mining and minerals processing industries. Hydrocyclones are applicable in dividing the feed solids continuously into fine (overflow) and coarse (underflow) fractions, which opens great possibilities for their use for two main purposes: pretreatment of slurry prior to filtration, to enable cost-effective filtration of the coarse underflow fraction with vacuum filters, and concentrating the valuable components present in ores (Bradley, 1965, Rushton et al., 2000). Reaching the required classification result is difficult in many applications, and therefore hydrocyclones are often installed in circuits involving recirculation back to the grinding stage and/or the use of more than one classification step (Boylu et al., 2010; Yianatos et al., 2002).

The pressure filtration properties of slurries are affected by several particle properties, for instance the size and shape of the particles, the shape of the size distribution, and interactions between the liquid and the particles (Mota et al., 2003; Wakeman, 2007; Yu et al., 2017). Filtration can be made easier by a couple of methods based on changing the properties of the slurry. Pretreatment methods, such as slurry thickening, flocculation and particle classification are typically used in the mining and minerals processing industries (Anlauf and Sorrentino, 2004; Hogg, 2000; Rushton et al., 2000). When the feed slurry contains very fine particles, which make the filtration challenging, the use of flocculants may be the most realistic, although not very cost-effective, option to improve the filtration capacity. Moreover, flocculation requires the addition of chemicals in the process, which needs to be avoided in many cases. Regarding the solid-liquid separation step, hydrocyclones are especially useful in cases where the particle size distribution of the feed is wide. This is because hydrocyclone classification enables narrowing the particle size distribution and reducing the fines content of the slurry in a single separation step. It has been reported in the literature (e.g. Kinnarinen et al., 2017) that reduction of the width of the distribution to produce a more porous cake would facilitate the

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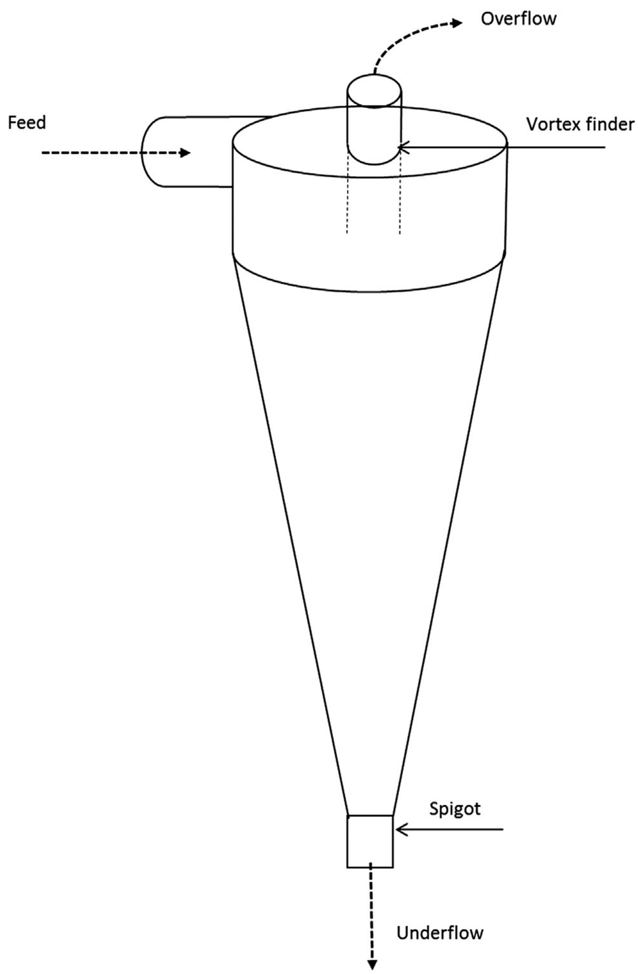

Fig. 1. Schematic diagram of a hydrocyclone.

filtration in some cases, in spite of the reduction of particle size.

The aim of this experimental study is to investigate how classification of a calcite slurry by using a hydrocyclone would affect the filtration properties of the underflow and overflow streams, and to compare those results with the original slurry, with respect to the required filtration area for a constant amount of feed slurry processed. The average specific cake resistances and the average porosities of the cakes are correlated with particle size characteristics, and the applicability of the Kozeny-Carman relationship for predicting the specific cake resistance is discussed.

2. Theory and calculations

2.1. Hydrocyclone

Fig. 1 shows a schematic diagram of a hydrocyclone. Several different design variables have an influence on the performance of the hydrocyclone (Bradley, 1965; Cilliers, 2000). Table 1 presents the main variables and how they affect the cyclone performance. In Table 1, D50 is the cut size corresponding to the particle size which has 50% probability to go to the underflow or the overflow, d_c is the diameter of the hydrocyclone, d_{VF} is the diameter of the vortex finder, d_{UF} is the diameter of the underflow spigot, h is the free vortex height, i.e. the distance from the bottom of the vortex finder to the top of the underflow spigot, and c_F is the volumetric solids concentration of the feed. The solids concentration of the feed slurry plays an important role in hydrocycloning. Increasing the solids concentration in the feed slurry increases the classification efficiency and the cut size D_{50}, but decreases

Table 1
Influence of hydrocyclone parameters and operating variables on the result of classification. Plus signs indicate an increasing effect, whereas minus signs indicate a decreasing effect when the parameter or variable value is increased, according to Cilliers (2000).

Parameter[a]	Throughput	Cut size D_{50}	Classification sharpness
d_C	+	+	+
d_{VF}	+	+	+
d_{UF}	+	−	−
d_F	+	−	−
Cone angle	Not comparable	+	+
h	+	+	+
Pressure drop	+	−	+ or −
c_F	+	+	−

[a] d_C is the diameter of the cyclone, d_{VF} the diameter of the vortex finder, d_{UF} the diameter of the underflow spigot, d_F the diameter of the feed, h the free vortex height and c_F the volumetric solids concentration of the feed.

the sharpness of the classification (Bradley, 1965; Cilliers, 2000; Lee, 2014). This effect is known as hindered settling, in which a higher number of particles moves outwards while the water flows towards the cyclone axis (Braun and Bohnet, 1990). The sharpness of the classification can be seen in the efficiency curve, which shows a percentage of a certain size of feed material that is recovered to the coarser underflow stream. A steep curve indicates sharp classification. Increasing the diameter of the vortex finder and the cyclone body increases the throughput volumes at a given pressure difference and the D_{50} values, as well as the sharpness of classification. The behavior of pressure drop is not so straightforward. An increase in the pressure drop increases the classification efficiency of the hydrocyclone and shifts the cut size D_{50} towards smaller particles, but it does not automatically result in sharper or gradual classification. Furthermore, it seems that the rheology of the slurry does not have a significant effect on the throughput, water split and classification sharpness of the hydrocyclone, which suggests the use of a rheology modifier to be a favorable option to modify the cut size D_{50} (Tavares et al., 2002). On the other hand, Kawatra et al. (1996) report that the viscosity of the slurry has a significant effect on the classification. The changes in the solid concentration have been mentioned already, but the temperature and chemicals, among other factors, can also change the viscosity, and therefore change the cyclone performance (Cilliers et al., 2004; Kawatra et al., 1996). Despite the large number of influencing factors, computational fluid dynamics (CFD) and empirical modelling can be applied successfully in the performance evaluation of hydrocyclones (Cullivan et al., 2004; Hwang and Chou, 2017; Neesse et al., 2004a, 2004b; Neesse and Dueck, 2007; Nowakowski et al., 2004; Schuetz et al., 2004).

2.2. Pressure filtration

Cake filtration processes are greatly affected by the size of the solid particles, small particles being more difficult to separate than coarser ones (Kinnarinen et al., 2015; Wakeman, 2007). The particle mean diameter in filtration studies is usually defined on the basis of the surface area or volume. The Sauter mean diameter $D_{[3,2]}$ (m), i.e. the surface mean diameter, is defined as (Allen, 2003):

$$D_{[3,2]} = \frac{\sum_{i=1}^{n} D_i^3 \nu_i}{\sum_{i=1}^{n} D_i^2 \nu_i} \quad (1)$$

where D_i is the diameter of a particle (m) and ν_i is the proportion of particles in the particle size fraction i.

Additionally, the volume mean diameter $D_{[4,3]}$ (m) is defined with the following equation:

$$D_{[4,3]} = \frac{\sum_{i=1}^{n} D_i^4 \nu_i}{\sum_{i=1}^{n} D_i^3 \nu_i} \quad (2)$$