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Reduction of the width of particle size distribution to improve pressure filtration properties of slurries

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A B S T R A C T

The filtration properties of mineral slurries depend for instance on the properties of the solid particles and on the way how these particles arrange themselves when the filter cake is formed. In cake filtration applications, the focus is often on particle size instead of the shape of particle size distribution (PSD). The aim of this experimental study is to demonstrate the influence of the width of PSD on the properties of the filter cake in the pressure filtration of Ni-Cu mine tailings. Modification of PSD is performed by using a stirred media mill at various operational conditions. The results show that not only particle size should be considered when the filtration properties are evaluated: a significant reduction of the average specific cake resistance (>60%) and increase of the average porosity (almost 30%) can be achieved by stirred media grinding at optimal conditions, in spite of reducing the median particle size. On the other hand, the selection of unfavorable grinding conditions may cause substantial increase in cake resistance. Above all, the results imply that the size of particles in the coarse end of PSD should be reduced while avoiding grinding of the finest particles. This seems to be obtainable by paying special attention to the size of the grinding medium. The main outcomes of this study will help in reducing the energy consumption of dewatering of tailings to be disposed of, and recovering valuable elements from tailings deposited in ponds, requiring the use of optimized grinding circuits and solid-liquid separation operations. However, the benefits obtained in the filtration stage should overcome the increased costs caused by the installation and energy consumption of the grinding systems. This means that the demonstrated grinding method may be profitably utilized in industrial scale only when the material is easy to grind and the filtration properties can be significantly improved, or when the filtration plant is the main bottleneck of the process.

1. Introduction

Wet grinding operations in minerals processing produce slurries where particle size distribution (PSD) of solids is optimized with respect to the quality of the final product and requirements of the subsequent unit operations, such as concentration by froth flotation and dewatering. Solid-liquid separation, performed for instance with vacuum or pressure filters, is routinely carried out before thermal drying of the product. The filter cake is basically a porous bed consisting of particles of non-uniform sizes and shapes and pores between them. The pores, i.e. voids, of the bed form a complex, randomly arranged network which is difficult to characterize with respect to size and shape (Lin and Miller, 2000a, 2000b, 2004). The importance of particle size and shape in cake filtration is widely recognized in the literature. Small particles are known to cause high resistance to filtration (Wakeman, 2007), which increases the cost of separation and drying (Basim and Khalili, 2015), and some non-spherical particle shapes have been reported to increase the compressibility and porosity of the filter cake (Bourcier et al., 2016). Among the most common statistical particle sizes used to describe the particle size of solids are the surface area -based Sauter mean diameter D[3,2], the median diameter D_{50}, and the volumetric mean diameter D[4,3] (Allen, 2003). The basic equations relating the properties of the filter cake to its permeability, such as the Kozeny-Carman equation (see e.g. Svarovsky, 1981; Ripperger et al., 2012; Osterroth et al., 2016), include not only the (surface area-based) particle size of the solids but also average bed porosity as key parameters. The assumption of monosized spherical particles forming an incompressible cake is typically used. When using these equations for experimental data the most influential reasons behind changes in cake porosity, such as the width of PSD and the particle shape distribution, are often not discussed at all. Too little attention has been paid to the influence of the particle size distribution on the separation characteristics of industrial mineral suspensions. Additionally, the effects of grinding

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parameters on the filtration properties of the suspension have been rarely discussed in the literature.

The main objective of this paper is to investigate the effect of the reduction of particle size on pressure filtration properties. The study aims at demonstrating that the reduced width of particle size distribution can help to overcome the negative effect on filtration caused by fine particles, and lead to a significantly improved filtration performance. An industrial sample of mine tailings is used as model suspension in order to ensure the practical relevance of the study.

2. Materials and methods

2.1. Characterization of slurry

The slurry sample was received from a nickel-copper mine. Table 1 presents the main characteristics of the slurry, including the density of the slurry and solids, the solids content of the slurry, and selected particle sizes of volumetric undersize distribution. The density of the slurry was measured on the basis of the mass and volume of the slurry sample, the solids content of the slurry was measured by drying the slurry at 105 °C to dryness, and the density of the solids was determined by using a liquid pycnometer. All particle size distributions presented in this paper were measured with a Malvern Mastersizer 3000 laser diffraction particle size analyzer.

The variations in the size and shape of particles in a dried slurry sample are illustrated by an image (Fig. 1) taken with a JEOL JSM-5800 scanning electron microscope. As can be observed, the particle shapes are very irregular and differ considerably from the perfectly spherical shape that is assumed in most theoretical approaches related to cake filtration. The particle shape distributions of selected samples, measured with Malvern Morphologi G3, are discussed in Section 4.4.

2.2. Grinding with a stirred media mill

The particle size distribution of the slurry solids was modified by using a vertical stirred media mill (Vollrath Salomix) described in closer detail by Kinnarinen et al. (2015). The experimental variables included (1) diameter of the glass beads (1–3 mm), (2) grinding time (5–15 min), and (3) stirring speed (300–700 rpm). The volume of the grinding vessel was approximately 5 dm^3, and the mass of slurry and glass beads in all tests was 2.2 and 3 kg, respectively. The total number of experiments was 31. The experimental plan, as well as the obtained grinding results are shown in Table 2. The definitions of the particle mean diameters and specific surface area are given below in Section 3. In this paper, the influence of each grinding variable on the particle size is discussed only from the point of view of the subsequent pressure filtration.

2.3. Pressure filtration

The slurry samples were filtered at room temperature with a Nutsche pressure filter at pressure differences of 2, 4, and 6 bar. The mass of each batch of slurry fed into the cylindrical filter chamber with a total volume of 350 cm^3 and a diameter of 52 mm was 250 ± 1 g. Discs made of pure cellulose (T-1000, Pall Corporation) were used as filter media after careful wetting in reverse osmosis quality water. An automatic data recording system was used to record the mass of the filtrate and the filtration pressure once a second during the filtration. After each test, the filter cake was dried in an oven at 105 °C to total dryness in order to calculate the solid content and further also the porosity of the cake.

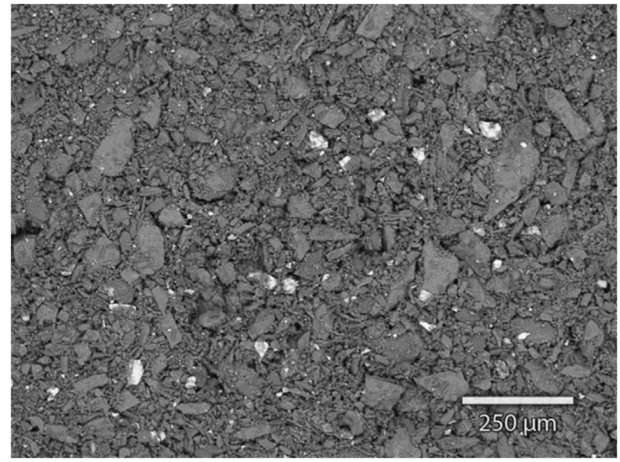

Fig. 1. SEM image of a dried slurry sample.

3. Theory

The Sauter mean diameter $D[3,2]$ (m) and the volume mean diameter $D[4,3]$ (m) are defined as (Allen, 2003):

$$D[3,2] = \frac{\sum_{i=1}^{n} D_i^3 v_i}{\sum_{i=1}^{n} D_i^2 v_i} \tag{1}$$

$$D[4,3] = \frac{\sum_{i=1}^{n} D_i^4 v_i}{\sum_{i=1}^{n} D_i^3 v_i} \tag{2}$$

where D is the particle diameter (m) and v_i is the proportion of particles in the size fraction.

When the volume-based specific surface area S_v ($m^2\,m^{-3}$) is calculated for spherical particles using the data obtained by a particle size analyzer, the only particle property required for the calculation is the Sauter mean diameter:

$$S_v = \frac{6}{D[3,2]} \tag{3}$$

The weight-based specific surface area S_w ($m^2\,kg^{-1}$) is calculated using Eq. (4).

$$S_w = \frac{S_v}{\rho_s} \tag{4}$$

The average specific cake resistance for constant pressure filtration is calculated with equations based on Darcy's law (Darcy, 1856). The flow rate through a filter cake and a filter medium is obtained from Eq. (5):

$$Q = \frac{\Delta p A}{\alpha \mu w + \mu R_m} \tag{5}$$

Table 1
Main characteristics of the tailings slurry.

ρ_{slurry} (kg/m^3)	C_s (wt.%)	ρ_s (kg/m^3)	D_{10} (µm)	$D[3,2]$ (µm)	D_{50} (µm)	$D[4,3]$ (µm)	D_{90} (µm)
1098	14.9	3130	1.73	4.71	13.9	24.0	61.6