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Technical note

Prediction of pressure filtration characteristics of $CaCO_3$ suspensions ground in a vertical stirred media mill

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ABSTRACT

Cake filtration is an important unit operation in the processing of minerals and pigments. The filtration characteristics are strongly dependent on the upstream processing of the ore, such as grinding parameters. This study aims at empirical investigation of the influence of key stirred media milling variables on the pressure filtration characteristics of calcium carbonate. Various regression models are presented and evaluated with respect to their statistical significance. The results show that all the grinding variables have a statistically significant influence on the average specific cake resistance, but the predictability of the models is not very good unless combined and polynomial terms are considered.

1. Introduction

The need for fine particles for various applications has increased recently in many industries, such as ceramics, minerals, pigments, cosmetics, electronics, and pharmaceutical industries (Breitung-Faes and Kwade, 2013; Inam et al., 2011; Choi and Choi, 2003). Grinding with stirred media mills has been proven to be an excellent alternative for the production of fine particles of the preferred size distribution.

In stirred media grinding, several factors have an influence on the obtained fineness of the product. These factors include, but are not limited to (1) the size of the mill, (2) the tip speed of the stirring element, (3) the rheology and solids concentration of the slurry, and (4) the size and density of the grinding beads (Becker et al., 2001; Inam et al., 2011; Garcia et al., 2002; He and Forssberg, 2007; Ohenoja et al., 2013a). High speed of the mill and the use of relatively small beads have been observed to produce narrower particle size distribution (Wang and Forssberg, 2000), but the optimal size of the beads depends on the feed size of the ground material (He and Forssberg, 2007). When the feed consists of fine particles, the grinding performance can be improved by the use of small beads (Ohenoja et al., 2013b), while the grinding of coarse particles is performed more efficiently by using coarse grinding media (Jankovic, 2003).

After the wet grinding stage, mechanical dewatering by cake filtration techniques is often performed in order to remove water from the product. A general trend in the mining industry has been that the flotation concentrates have become finer than they were before, which is mainly due to the increasing complexity and decreasing quality of the available ores (Townsend, 2003). This has increased the need to use great pressure differences to enable efficient separation. Cake filtration processes are affected by a great number of factors, including the solids concentration of the slurry, particle size distribution, particle shape, and surface charge of the particles, as well as the properties of the filter medium (Tarleton and Willmer, 1997; Wakeman, 2007). Due to these factors and the compressibility of the filtered materials, i.e. the increase of the average specific cake resistance with the applied pressure, the cake filtration processes are difficult to predict theoretically. Therefore, empirical modeling of cake filtration is often a more reasonable approach.

In this study, ground calcium carbonate (GCC) is used as the model substance. The aim is to increase awareness of the effect of grinding parameters on the pressure filtration properties of the ground suspensions. Various regression models are utilized as tools in this empirical evaluation.

2. Theory and calculations

The used regression models are introduced below. The theory of constant pressure filtration has been presented in earlier literature for instance by Svarovsky (1981).

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The models described in Eqs. (1)–(4) were used for the prediction of the average specific cake resistance α_{av} (Y). In all the models presented below, X_1, X_2, X_3 and X_4 represent the bead size, grinding time, grinding speed and filtration pressure, respectively. The regression coefficients are represented by symbols β_1–β_{14}, while β_0 stands for the Y-intercept.

The simplest linear model used to describe the filtration properties was

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 \quad (1)$$

All possible combined effects were then added to improve the prediction as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_1 X_2 + \beta_6 X_1 X_3 + \beta_7 X_2 X_3 + \beta_8 X_1 X_4 + \beta_9 X_2 X_4 + \beta_{10} X_3 X_4 \quad (2)$$

When also the quadratic terms were added, the model became

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_1 X_2 + \beta_6 X_1 X_3 + \beta_7 X_2 X_3 + \beta_8 X_1 X_4 + \beta_9 X_2 X_4 + \beta_{10} X_3 X_4 + \beta_{11} X_1^2 + \beta_{12} X_2^2 + \beta_{13} X_3^2 + \beta_{14} X_4^2 \quad (3)$$

Evaluation of the statistical significance revealed that some terms in Eq. (3) were not statistically significant. After the deletion of the unnecessary terms, the model became

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_1 X_2 + \beta_6 X_1 X_3 + \beta_7 X_2 X_3 + \beta_8 X_3 X_4 + \beta_9 X_3^2 \quad (4)$$

Table 1
Coefficients β_i of the regression models defined in Eqs. (1)–(4).

Eq. (#)	Modeling of α_{av}: coefficient $\beta_i \times 10^{10}$ (m kg^{-1})									
	B_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}–β_{14}
(1)	17.7	−3.33	6.65	8.74	2.21	–	–	–	–	–	–
(2)	17.7	−3.33	6.65	8.74	2.21	−2.13	−1.47	3.00	−0.49	0.69	1.05
(3)	17.5	−3.33	6.65	8.74	2.21	−2.13	−1.47	3.00	−0.49	0.69	1.05; −1.05; −0.56; 2.46; −0.44
(4)	16.5	−3.33	6.65	8.74	2.21	−2.13	−1.47	3.00	1.05	2.13	–

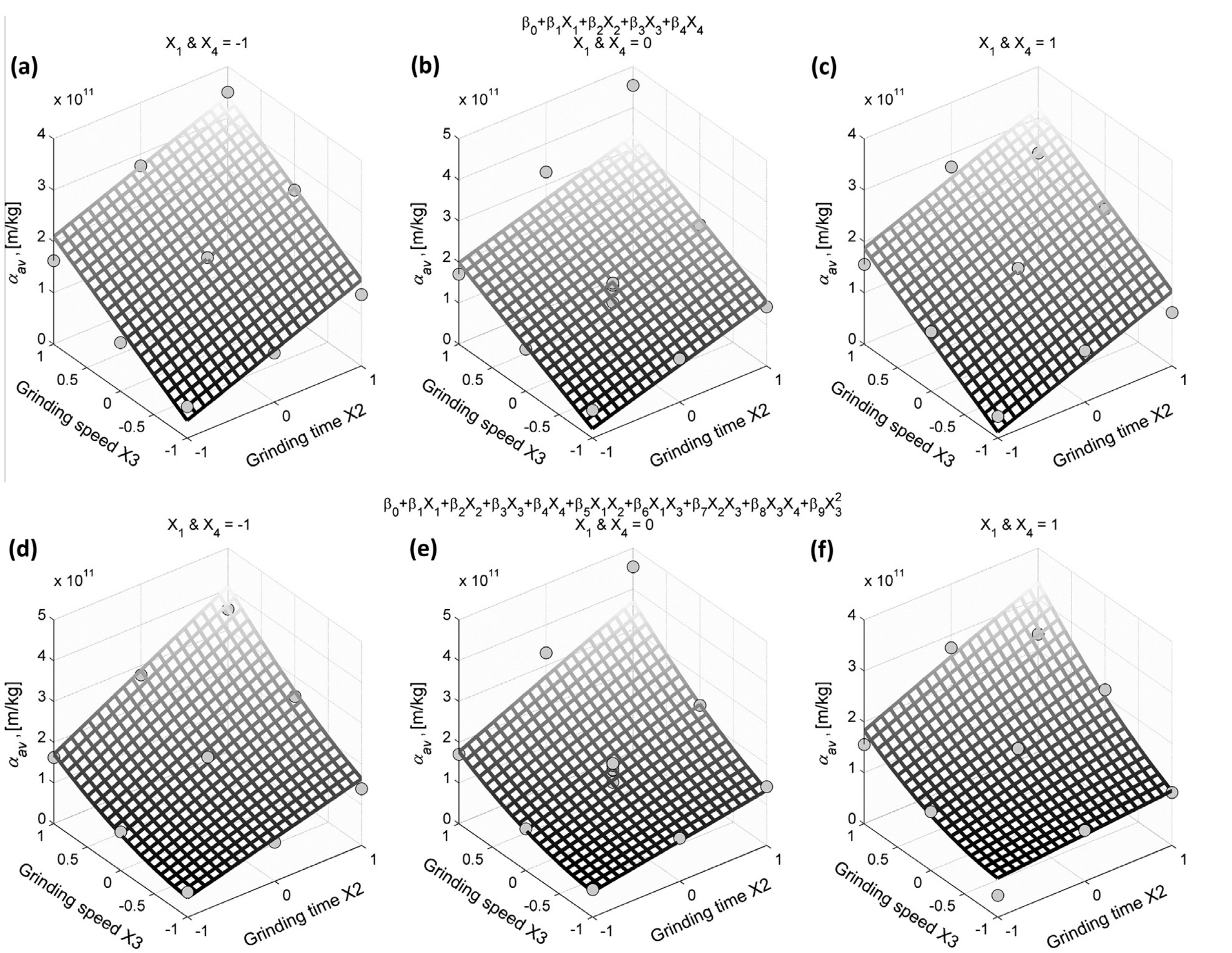

Fig. 1. Visualization of a linear regression model (Eq. (1)) incorporating the grinding speed and time as the variables when the levels of bead size and filtration pressure increase from the minimum to the maximum (a–c). Visualization of the statistically improved regression model (Eq. (4)) incorporating the grinding speed and time as the variables when the levels of bead size and filtration pressure increase from the minimum to the maximum (d–f). The spheres describe the measured values of α_{av}, and the grid describes the modeled values.