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An investigation on laboratory Knelson Concentrator separation performance: Part 2: Two-component feed separation modelling

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ABSTRACT

In the previous study, a mathematical model was proposed to predict retained mass inside a laboratory Knelson Concentrator bowl. In this part, a model is proposed to describe the particle separation performance of the laboratory Knelson Concentrator. The separation model considers the main forces (fluid drag force, F_d, centrifugal force, F_c, and buoyancy force, F_b) acting on particles inside the concentrating bowl, which are functions of material properties as well as the operating condition parameters. Several materials with different densities including magnetite, zinc, ferromolybdenum, lead, and tungsten were used as valuable components to simulate minerals with the same densities in two-component synthetic feeds with various size fractions. The modelling of component separation in the Knelson Concentrator was performed based on the ratio of $F_d/(F_c-F_b)$. Based on an extensive experimental database, practical and simple models were proposed as predictors of recovered mass of valuable components from tailings and the mass of quartz (as gangue) in the Knelson Concentrator versus the ratio of $F_d/(F_c-F_b)$ for quartz.

1. Introduction

Knelson Concentrators are gravity concentration devices that are commonly used in gold recovery from both alluvial and primary ore deposits (Coulter and Subasinghe, 2005; Zhang, 1998). The device is installed in the grinding circuit of a gold operation, where the metal often accumulates due to its grinding and classification behaviour (Banisi et al., 1991; Coulter and Subasinghe, 2005).

Laplante (2000) has devised a method to evaluate the feasibility of employing a gravity gold circuit based on the Gravity Recoverable Gold (GRG) content. This method can be used to separate particles smaller than 6 mm and, nowadays, it is a well-accepted method of gravity separation for gold and other heavy materials.

Laplante et al. (1996) investigated the effects of the feed rate, density and size, and the fluidization water flow rate on the recovery of gold in a 3.5-inch laboratory Knelson Concentrator. They reported that recovery decreased with an increasing feed rate and the effect of the fluidization water pressure was found to be minimal, with the maximum gold recovery achieved at 33 kPa. The optimum pressure of fluidizing water is a function of the feed size distribution and density. The gold recovery varies with the fluidizing water for different feed sizes. The recovery of gold decreased for fine sizes but it was clearly dependent on the feed gold grade (Laplante et al., 1996).

Putz (1994) and Vincent (1997) discussed the rationale of using the LKC (Laboratory Knelson Concentrator) to evaluate the circuit performance, when the ore, equipment or flow sheet limits gold recovery. Typically, the 3-inch unit, or LKC, is used as an instrument to measure the GRG content of 5- to 50-kg samples (Laplante, 1998; Zhang, 1998).

The use of recovery as a predictor of KC performance is limiting. Recovery is related to the ratio of mass of minerals recovered in the concentrate to the mass of minerals in the feed. The KC operates in a batch mode; hence, at some point, the concentrate rings in the bowl reach their full capacity. Thus, incoming mineral particles bounce off the concentrate bed and leave the unit, leading to a decrease in the recovery. If the recovery is to be used as a predictor, it is important not to over feed the KC. In other words, the fixed volume of the Knelson Concentrator bowl limits the amount of gold collected, constraining the cycle time in batch plant operations (Coulter and Subasinghe, 2005).

The partition curve relates to the partition coefficient or partition number, i.e. the percentage of the feed material of a particular density, which reports to either the sink product (generally used for minerals) or the float product (generally used for coal), to density. It is exactly analogous to the classification efficiency curve, in which the partition coefficient is plotted against size rather than density (Kapur, 1983; Wills and Napier-Munn, 2006).

Generally, the partition values are the unknown function of the characteristic, which is taken as the separation criterion (Pyka and Wierzchowski, 2012).

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Partition value = f (physical property taken as the separation criterion; e.g. density or size of the particle etc.)

The ideal partition curve reflects a perfect separation in which all particles having a density higher than the cut density report to sinks, and those lighter reports to floats. There is no misplaced material. The partition curve for a real separation shows that efficiency is the highest for particles of density far from the cut density and decreases for particles approaching the cut density. The area between the two curves is called the "error area" and is a measure of the degree of misplacement of particles to the wrong product. Many partition curves give a reasonable straight-line relationship between the partition values of 25% and 75%, and the slope of the line between these distributions is used to show the efficiency of the process (Sripriya et al., 2001; Wills and Napier-Munn, 2006).

Many empirical mathematical models of the Tromp curve are now available. These range from the well-known statistical distribution functions, e.g. Gaussian, log-normal, Rosin-Rammler, Gaudin-Schuhmann, to more recent and more complicated functions containing 4 or 5 parameters. As summarized by Reid et al. (1985), the latter class of models includes arctan, quasi-normal integral, modified normal integral, hyperbolic tangent and modified hyperbolic tangent functions, as well as a modified Weibull distribution functions (Tamilmani and Kapur, 1986).

A mechanistic model was developed by Coulter and Subasinghe, 2005 to describe the operation of a Knelson Concentrator. The data obtained in their study were representative of an individual particle size distribution, only for two different densities at a limited range of rotational speed. They fitted a Weibull distribution to their data using a least squares approach as follows (Coulter and Subasinghe, 2005):

$$V = V_0.\ exp\left[-\left(\frac{X}{X^*}\right)^n\right] \tag{1}$$

where V is the volume collected (cm^3), V_0 is the maximum volume of material the KC bowl can accommodate under a given set of operating conditions (cm^3), X^* is the critical value of X at the transition between the two regions and n is the exponent.

$$V_0 = 4.3 \times 10^3 \rho d - 2.15\rho + 31.23 (R^2 = 0.98) \tag{2}$$

while n may be considered a constant, as none of the operating variables in the regression shows a statistically significant effect (Coulter and Subasinghe, 2005).

$$n = 3.25 + 4.55 \times 10^{-2}\omega - 0.8\rho + 5.85 \times 10^5 d^2 - 2.1 \times 10^{-4}\omega^2 (R^2 = 0.92) \tag{3}$$

The volume of a material V_i, which is mixed with others and fed to the Knelson Concentrator, can be calculated by Eq. (4):

$$V_i = V_{0i}.\ f_i.\ exp\left[-\left(\frac{X_i}{X_i^*}\right)^n\right] \tag{4}$$

where V_{0i} is the maximum volume of material retained under a given set of conditions, f_i is the volume fraction of mineral in the feed, X_i^* is the critical value of X_i at the transition between two regions and n is an exponent. The V_{0i} parameter is dependent mainly on particle density and the interactive effect between density and size. Using Eq. (4), the volume recoveries of minerals, both in size and density mixtures, were determined for a range of operating conditions (Coulter and Subasinghe, 2005).

The objective of the present study is the derivation of an empirical model of material separation inside the Knelson Concentrator in terms of particle characteristics (size and density) and operating condition parameters (rotational speed and fluidization water pressure, etc.). This model can be used, firstly, to predict the separation of GRG to marginal-GRG material ranges from gangue. Fig. 1 shows this range for a gangue composed of silicates, whose density is approximately 2.65 g/cm^3. Secondly, this model can predict the separation of other minerals with various sizes and densities lower than gold by using the Knelson Concentrator. For example, these include gold and platinum group metals (PGM) containing minerals such as cooperate PtS (SG = 10.10), sperrylite PtAs (SG = 10.60), maslovite PtBiTe (SG = 11.23) and Auricupride Cu_3Au_2 (SG = 11.5).

In Fig. 1, if a middling particle consisted of quartz and gold includes gold grains with a size of 50, 100, 150 and 200 μm and a volumetric ratio of 10, 20, 40 and 60%, then the size and density of the middling particle would be as given in Table 1.

2. Materials and methods

2.1. Materials

It has been previously shown that synthetic tungsten/quartz feed can accurately mimic gold ore under gravity test conditions (Kökkılıç et al., 2015). In this study, synthetic feeds were used to mimic the composition of ores, containing valuable components.

In order to separate middling particles or heavy mineral particles with different densities, magnetite (Sangan iron ore mine, Iran), zinc (Cirda Co., China), ferromolybdenum (Zanjan Boronz Co., Iran), copper (Khorasan Powder Metallurgy Co., Iran), lead (National Iranian Lead and Zinc Co, Iran) and tungsten (Eurotungsten Co., France) were used to simulate these particles including gold with the same densities and various size fractions (Table 2). These materials and their sizes were selected, based on the density and size of the middling particle calculated in Table 1. The synthetic feed of quartz/magnetite before mixing is shown in Fig. 2.

Quartz (Silica Sand MFG Co., Iran) was used as the low-density gangue (2.65 g/cm^3). Hydrochloric and nitric acid washing were done to remove any impurities from the samples. Electron Probe Micro Analyzer (EPMA, Cameca S∗100) micrographs and Energy Dispersive X-ray (EDAX) analysis of the particles are given in Fig. 3. As shown in Fig. 3, particles are rounded or unrounded with almost a spherical shape.

2.2. Experimental protocol

2.2.1. Knelson Concentrator

All the tests were conducted using a laboratory Knelson Concentrator of Manual Discharge type with a bowl diameter equal to 3 inches (KC-MD3) at the Iran Mineral Processing Research Center (IMPRC).

2.2.2. Separation tests

The tests were carried out in order to find the recovery of valuable components using an experimental protocol as defined below:

- Samples of synthetic feed were prepared by mixing quartz and valuable components with a volume ratio of 4% in each size fraction (Table 2).
- The volume of valuable components in the synthetic feed was 6 cm^3.
- The solid and water feed flow rate were kept constant at 300 g/min and 700 cm^3/min, respectively, because the effects of these two parameters on separation process were negligible.
- The tests were done on three size fractions of each valuable component in the fluidizing water flow rates of 15, 10 and 5 L/min. and bowl rotational speeds of 1931, 1675 and 1305 rpm.
- To validate the proposed separation model, several tests were done outside the range of previous operating conditions and by using other valuable components such as copper and tungsten with different densities.
- At the end of each test, the concentrate was collected, dried and weighed, and then prepared for analysis.