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An investigation on laboratory Knelson Concentrator separation performance: Part 3: Multi-component feed separation modelling

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ABSTRACT

In the previous study, mathematical models were proposed to describe the mass of the valuable component and quartz recovered in a Knelson Concentrator bowl based on experiments conducted on two-component synthetic feeds. In continue, a series of experiments were done on multi-component synthetic feeds which were a mixture of five valuable components (i.e., magnetite, zinc, copper, lead and tungsten) and quartz to obtain a general recovery models. In this part, the results of material characterization, details of experimental protocol and finally multi-component recovery models will be presented which are based on material properties and operating condition parameters. The observed results indicate that the best operating condition to obtain maximum recovery of valuable component and highest grade of concentrate is at values higher than 250 for $F_d/(F_c{-}F_b)_Q$.

1. Introduction

Knelson Concentrator (KC) as a centrifugal concentrator is mainly used for recovery of gold and platinum and may be used for recovery of heavy minerals in alluvial mining, grinding and flotation circuits products (Coulter and Subasinghe, 2005; Kelson and Jones, 1993; Laplante et al., 1994; Zhang, 1998). The device is most commonly installed (Banisi et al., 1991) in the grinding circuit of a gold operation, where gold often accumulates due to its grinding and classification behaviour (Coulter and Subasinghe, 2005).

Laboratory Knelson Concentrator operates in a batch mode and the bowl has a fixed capacity. Therefore, to use the recovery of valuable component in the bowl to prepare the model, the Knelson Concentrator should not be operate in the overloading or overfeeding conditions (Coulter and Subasinghe, 2005).

Knelson Concentrator was used for beneficiation of chromite ore. Full factorial experimental design and response surface methodology were applied to determine the effect of operational parameters, namely: feed rate, centrifugal force and fluidization water flow rate on the efficiency of the Knelson Concentrator. The quadratic models were proposed to predict the concentrate grade and recovery. The results show that all the parameters affect the grade and recovery of the concentrate to some degree. However, the fluidization water rate was found as the most effective parameter (Gul Akar Sen, 2016). A modified 3-inch laboratory Knelson Concentrator was used to investigate operating with dry synthetic feed (quartz-magnetite) and using air to replace water as the fluidization bed. The response surface method and central composite design techniques were used to design the experiments and for modelling and optimization the experimental variables being the motor power, air fluidizing pressure and solid feed rate. The results show that the motor power had a greatest impact among three variables (Kökkılıç et al., 2015; Zhou et al., 2016). Coulter and Subasinghe, 2005 presented a model function to predict the volume of a material retained in the KC bowl using fitting Weibull distribution on the experimental data.

Should a particle be retained in the bowl, the centrifugal force (F_c) must overcome the drag (F_d) and the buoyancy (F_b) forces. Where three forces are given by:

$$F_c = \left(\frac{\pi}{6}\right)D^3\rho_s r\omega^2 \tag{1}$$

$$F_d = P_w A_p = P_w\pi\left(\frac{D}{2}\right)^2 \tag{2}$$

$$F_b = \left(\frac{\pi}{6}\right)D^3\rho_w r\omega^2 \tag{3}$$

where r is the radial position of the particle of size D, ρ_s its density and ω the angular velocity, P_w is the fluidization water pressure (gauge pressure) and ρ_w is the density of water.

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In the previous study, F_d was defined as the fluidization water pressure (gauge pressure), P_w multiplied by the projected area, A_p of a spherical particle hydraulically equivalent to the solid particle. It is noted that the fluidization water pressure (gauge pressure), P_w, is the sum of hydrostatic and hydrodynamic pressures exerted on a particle in the rotating bowl.

Present authors proposed a model for the retained mass of materials in the KC bowl by definition of a new ratio of $F_d/(F_c{-}F_b)$. A Weibull function was used to obtain the model based on a large data base of experiments using different materials with various particle sizes and densities under various operating conditions. It was observed that for the $F_d/(F_c{-}F_b)$ value less than 23, overfilling occurs in the bowl and this value was selected as a critical value (Ghaffari and Farzanegan, 2017a).

Also, authors derived the models to describe the separation performance in the Knelson Concentrator. In Part 2 of this article, models functions were proposed for valuable components and quartz (as tailings) recovered in the bowl of KC in terms of particle characteristics (size and density) and operating parameters (rotational speed and fluidization water pressure) (Ghaffari and Farzanegan, 2017b).

The models for mass of recovered valuable component, Eq. (4), and quartz, Eq. (5), in the KC bowl were proposed based on the $F_d/(F_c{-}F_b)_Q$. Two modelling methods were used to fit the curves on experimental data. Finally, two models were proposed for mass of recovered valuable component and quartz using the Weibull function (Ghaffari and Farzanegan, 2017b).

$$R_{V.C.,i,j} = \rho_i\left[R_{V.C.max}{-}b\exp\left[-c\left(\frac{3P_w}{2(\rho_Q{-}\rho_w)D_{i,j}r\omega^2}\right)^d\right]\right] \tag{4}$$

$$R_{Q,j} = \rho_Q\left[R_{Qmax}{-}b\exp\left[-c\left(\frac{3P_w}{2(\rho_Q{-}\rho_w)D_{Q,j}r\omega^2}\right)^d\right]\right] \tag{5}$$

The previous studies were done on a synthetic feed consisting only two components such as quartz-magnetite (Coulter and Subasinghe, 2005) or quartz-tungsten (Kökkılıç et al., 2015; Zhou et al., 2016). The above-stated models, Eqs. (4) and (5), were derived based on many experiments on several two-component synthetic feeds consisting valuable components with various densities and quartz. Because particles with various densities exist together in an ore, therefore, the objective of this article is proposing models for valuable components and quartz recovered in the bowl, through further experiments on multi-component synthetic feeds which are a mixture of five valuable components and quartz. The models would be proposed in terms of particle characteristics and operating conditions parameters.

2. Materials and methods

2.1. Materials

The available literature shows that synthetic feeds have been used to mimic the compositions of ores containing valuable components and gangue (Laplante et al., 1995a,b; Laplante and Nickoletopoulos, 1997; Zhou et al., 2016). Therefore, to perform separation experiments by the Knelson Concentrator, mixture of magnetite, zinc, copper, lead and tungsten powders with quartz powder were used in 3 size fractions (Table 1). The volume ratio of sum of valuable components in the synthetic feed is 4%. The multi-component synthetic feeds consisted of quartz and five valuable components before mixing are shown in Fig. 1.

The sources of materials have been described in the previous parts of the article (Ghaffari and Farzanegan, 2017a,b). Quartz was used as the low-density gangue (2.65 g/cm^3). The quartz was washed by hydrochloric and nitric acid to remove any impurities in the experiments. Chemical compositions of the metals powders, magnetite and quartz are shown in Tables 2 and 3, respectively. X-ray diffraction (Philips X'Pert) spectra of the materials are demonstrated in Appendix A. Characterizations studies show that the materials used in experiments are pure and impurities are minimal and negligible.

Table 1
Materials used and their size fractions.

Material	Density (g/cm^3)	Size fraction (μm)		
Quartz	2.65 ± 0.01	−180 + 150	−212 + 180	−300 + 250
Magnetite	4.85 ± 0.03	−180 + 150	−212 + 180	−300 + 250
Zinc	6.54 ± 0.15	−180 + 150	−212 + 180	−300 + 250
Copper	8.76 ± 0.01	−180 + 150	−212 + 180	−300 + 250
Lead	11.11 ± 0.07	−180 + 150	−212 + 180	−300 + 250
Tungsten	18.25 ± 0.09	−180 + 150	−212 + 180	−300 + 250

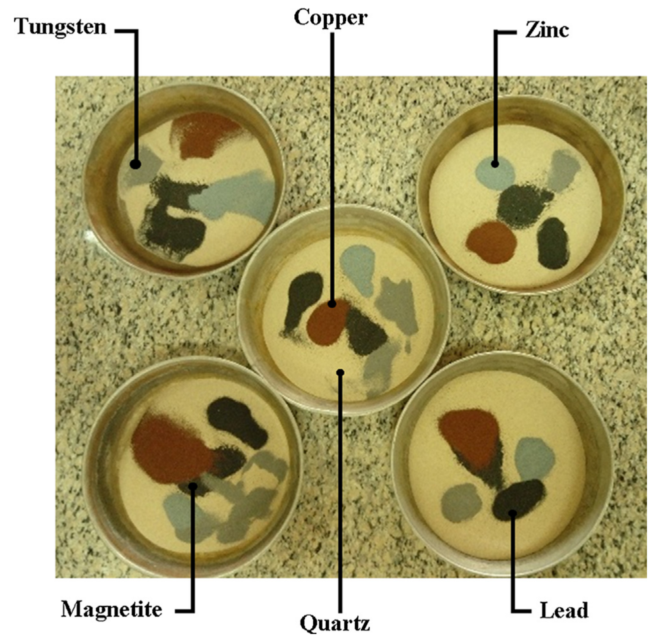

Fig. 1. The multi-component synthetic feeds consisted of quartz and five valuable components (before mixing).

2.2. Experimental protocol

2.2.1. Knelson Concentrator

The experiments were performed using a laboratory Knelson Concentrator of Manual Discharge type (KC-MD3) with a bowl diameter equal to 3 in. at the Iran Mineral Processing Research Center (IMPRC) by feeding a mixture of quartz and five valuable components with various densities and sizes in a batch mode.