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A study on the effect of particle size on coal flotation kinetics using fuzzy logic

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ABSTRACT

This paper investigates the effect of particle size on the flotation kinetics of coal in a batch flotation cell. The relationship between flotation kinetics constant and theoretical flotation recovery with particle size was estimated with nonlinear equations. Analysis of variance shows that varying of particle size is statistically significant on kinetics constant with approximately 96.5% confidence level however it is not significant on maximum theoretical flotation recovery (RI) in 95% confidence level. Using fuzzy logic method, a multi-input/single-output (MISO) fuzzy model with two input variables: particle size and time and one output variable: cumulative recovery was established to predict the effect of particle size on the flotation kinetics of coal in a batch flotation cell. Application of fuzzy model shows that the results of model fits well to the result of batch flotation and the fuzzy model can be applied to predict cumulative recovery of different coal particle size. The correlation coefficient (R^2) values of the proposed fuzzy model were 0.986, 0.993, 0.983, 0.977 and 0.972 for 37.5 μm, 112.5 μm, 225 μm, 400 μm and 625 μm average particle sizes, respectively.

1. Introduction

Froth flotation is a physicochemical method which is widely used in mineral processing technologies for the separation of finely ground valuable minerals from a mixture with gangue minerals initially present in a pulp. Since the cumulative recovery of a component in the concentrate is proportional to flotation time, the flotation process can be considered as a time-rate recovery process (Sripriya, Rao, & Choudhury, 2003; Yuan, Palsson, & Forssberg, 1996). Therefore, mathematical flotation models that incorporate both a recovery and a rate function can completely describe flotation time-recovery profiles. They provide an excellent tool to evaluate flotation tests.

The kinetics of flotation has been studied by many workers. Batch flotation test data in the literature support the first-order rate equation under reasonable operating conditions (Agar, Chia, & Requis, 1998; Çilek, 2004; Dowling, Klimpel, & Aplan, 1985; Harris & Chakravarti, 1970; Jameson, Nam, & Young, 1977; Mauzimi & Inoue, 1963; Oliveira, Saraiva, Pimenta, & Oliveira, 2001; Wills & Napier-Munn, 2006). A modified first-order rate equation of the form:

$$R = \mathrm{RI}[1 - \exp(-kt)] \tag{1}$$

is proposed, where R is the cumulative recovery after time t, k is the first-order rate constant (time^{-1}), t is the cumulative flotation time and RI is the maximum theoretical flotation recovery. RI (ultimate recovery) and k (first-order rate constant) are obtained from the model fit to an experimental recovery-time curve. They can be effectively used to evaluate variables affecting flotation process. In the derivation of this equation, it has been assumed that the only independent variable has been the concentration of floatable material, and that everything else has remained constant such as size and size distribution, bubble concentration, reagent concentrations, cell operation, etc. (Gupta & Yan, 2006; Labidi, Pèlach, Turon, & Mutjé, 2007; Larsson, Stenius, & Odberg, 1986).

It is recognized that coal particles in a flotation pulp possess a range of rate constants dependent on floatability (Ofori, O'Brien, Firth, & Jenkins, 2006). The effect of particle size on flotation rate has been known since the pioneering paper by Gaudin (1932). The results were presented mostly as recovery-size curves, in which the recovery from a particular size fraction was plotted against the average size of particles in that fraction (King, 1982; Mehrotra & Kapur, 1975; Trahar, 1981). Numerous researchers have studied the kinetics aspects of froth flotation paying special attention to particle size (Hernáinz & Calero, 2001; Loewenberg & Davis, 1994; Polat, Polat, & Chander, 2003; Radoev, Alexandrova, & Tchaljovska, 1990; Trahar & Warren, 1976; Uçurum & Bayat, 2007). However the exact relationship between the particle size and flotation rate is complex and not well understood, most probably due to the aggregation of fine particles in flotation (Al Taweel

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et al., 1986; Chander & Polat, 1995; Chander, Polat, & Polat, 1995; Humeres & Debacher, 2002).

This study has examined the effects of particle size on the coal flotation kinetics parameters (RI and k). A fuzzy logic model was developed to modeling the effect of particle size on the coal flotation kinetics. Fuzzy logic methodology has been proven to be effective for dealing with complex nonlinear systems with uncertainties that are otherwise difficult to model. The advantages of fuzzy logic compared to numerical methods are that they are speedy, simple and capable to learn from numerical results and it does not require a complex mathematical model (Wang, 1994).

2. Material and methods

A coal sample of about 50 kg was collected from the feed of the Zarand washery plant in Iran. The sample was screened at 0.85 mm for kinetics test. The collected sample was subsampled by coning and quartering to obtain a representative sample. In Table 1, Size distribution and ash analysis of the coal sample is provided.

Kinetics test were carried out in a Denver laboratory flotation machine. The impeller speed, and solids content were kept constant at 1000 rpm and 10% (by weight), respectively. The collector used in the kinetics test was gas oil (2.5 kg/t) and frother was pine oil (230 g/t). In flotation kinetics test, the pulp was first agitated in the flotation cell for 2 min, after which the required dosage of flotation reagents was added, and the slurry was conditioned for 5 min, Air was then introduced, and froth samples were collected after 10, 20, 30, 45, 60, 90, 120, 150, 210 and 270 s of flotation. After the final froth sample was collected, the machine was stopped. Size-wise ash analysis for the five fractions, −75, −150 + 75, −300 + 150, −500 + 300 and −850 + 500 μm was conducted for froth products and the tailings (the part that remained inside the machine). Using the results of yield and ash percentages of the concentrates collected at different time intervals along with tailing weight, the cumulative recoveries of non-ash materials for each fraction are calculated as follows:

$$R = Y(100 - A_c)/(100 - A_f) \quad (2)$$

where R is the combustible recovery, Y is the percentage yield of the concentrate and A_c and A_f are the percentage ash contents of the concentrates and the feed materials, respectively.

Table 1
Size analysis and size-wise ash content of the sample.

Size (μm)	Wt (%)	Ash (%)
−850 + 500	20.7	24.8
−500 + 300	13.2	22.4
−300 + 150	22.4	20.8
−150 + 75	15.9	21.1
−75	27.8	32.6
Total feed	100	25.2

3. Theory

Fuzzy logic or fuzzy set theory was first presented by Zadeh (1965). Many researchers have studied the modeling of complex systems since the introduction of fuzzy logic (Vitez, Wada, & Macario, 1996). The fuzzy theory provides a mechanism for representing linguistic constructs such as "many", "low", "medium", "often" and "few". In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. Many concepts are better defined by words than by mathematics, and fuzzy logic and its expression in fuzzy sets provide a discipline that can construct better models of reality (Ertugrul, 2008). In a classical set, an element belongs to, or does not belong to, a set. Because fuzzy sets describe vague concepts based on the premise that the elements used are not numbers but belong to words or the value of a linguistic variable, an element of a fuzzy set naturally belongs to the set with membership values from the interval [0, 1]. Fuzzy systems commonly have four components (Fig. 1): (1) a fuzzification process; (2) a rule base; (3) an inference engine, and (4) a defuzzification process. Fuzzification is a process that classifies numerical measurements into fuzzy sets. The rule base contains the " if ... then" rules that embody linguistic reasoning. An inference engine applies the rule base to the fuzzy sets to obtain a fuzzy outcome. A defuzzification procedure converts the fuzzy outcome to a crisp one.

A newly developed fuzzy logic model is defined in this study. It is assumed that batch flotation is a system with two input (particle size and time) and single-output (cumulative recovery). The process simulation is supported by software MATLAB7.6.0 using Fuzzy toolbox. This tool makes possible the definition of the membership functions, for the input and the output variables, with their desirable ranks. Fig. 2, shows input and output variables in the MATLAB environment.

The design of the applied fuzzy expert system followed the stages described below:

(a) Fuzzification or selection of the membership functions for the input variables.
(b) Design of the rule base, with rules that link up the input variables with the output variable. For this system multi-input/single-output rules were specified.

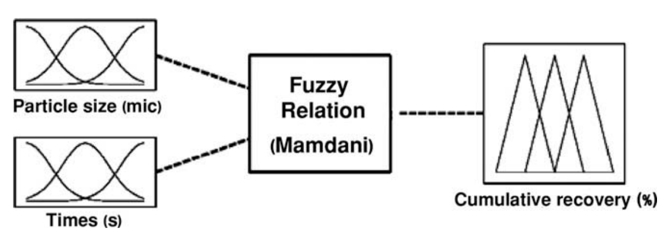

Fig. 2. Input variables and output of the model.

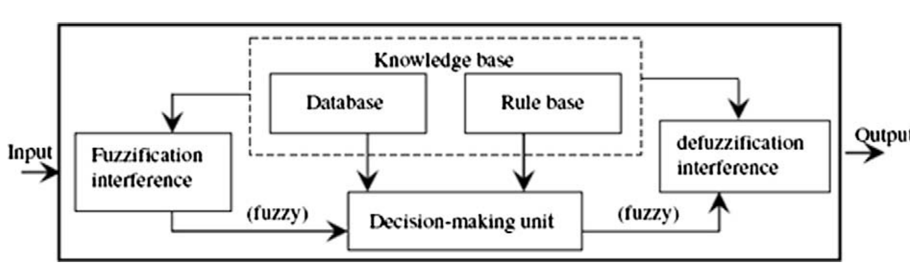

Fig. 1. General flowchart of fuzzy inference system (Jain & Martin, 1998).