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Interpretation of interaction effects and optimization of reagent dosages for fine coal flotation

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Abstract

The effect of three most important reagents for coal flotation namely sodium meta silicate, collector (kerosene) and frother (MIBC) was studied using 2^3 full factorial design. The regression models were developed using factorial experiment data to quantify the effect of sodium meta silicate, collector and frother and to predict grade and recovery of combustible material for different reagent conditions. The addition of sodium meta silicate increased the recovery without affecting the grade significantly. The MIBC addition reduce the surface tension at the liquid–vapor interface, which results in the production of finer bubble size distribution and thus improves flotation rates and recovery values. However, a finer bubble size distribution also increases water recovery, which results in a greater recovery of entrainable ash bearing particles and thus degradation of the product grade. The interaction between OH group of MIBC and hydrated mineral matter improves flotability of high ash coal particles and degrades the product grade further. The negative effect of kerosene and MIBC interaction on both grade and recovery could be due to the recovery of high ash coal particles in preference to low ash coal particles. The highest possible grade of product is 94.19% combustibles with 25.33% recovery. A product with 91.11% combustibles grade at 95.58% recovery was obtained at 0.1 g/kg sodium silicate, 0.4 g/kg collector and 0.075 g/kg frother from the coal fines tested.

Keywords: coal; flotation; interaction effect; optimization

1. Introduction

Flotation is one of the most complex mineral processing operations as it is affected by a very large number of variables. Many of these are beyond the control of the mineral engineer, and some cannot be even measured quantitatively with the available instruments. The relations between measured and controlled variables are intricately related. Sometimes simultaneously changing various component settings will reinforce a particular attribute. In addition, various component settings can cancel or counteract each other if changes are not chosen wisely. For coal fines (−0.5 mm), froth flotation is the most effective method of separating ash forming mineral matter from the

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carbonaceous material. Currently, froth flotation is the only effective and economical means of recovering −0.15 mm coal on an industrial scale (Aplan, 1999).

Coal is a heterogeneous mixture of carbon constituents and mineral matter. The hydrophobicity of the former depends upon the type of material (Aplan and Arnold, 1986) and the rank (Gutierrez-Rodriguez and Aplan, 1984). Microscopically, coal has a cross-link network structure of polymeric molecules (Iino, 2000) and macroscopically, it is made up of finely mixed discrete organic entities known as macerals (Jimenez et al., 1998). The coal is complex both physically and chemically, and often highly variable even when from the same source. So each time a bulk sample is received, a complete set of experiments is conducted using the classical method of treating one variable at a time.

The statistical design of experiments (Cochran and Cox, 1957; Daniel, 1976; Box et al., 1978; Akhanazarova and Kafarov, 1982) has several advantages over the classical method of treating one variable at a time. The full factorial experiment is method of design of experiments in which a statistical analysis is performed to evaluate the significance of the main and interaction effects as evaluated from the experimental results. In particular, they are used when several factors have to be studied in order to determine their main effects and interaction. The experiments can be conducted in an organized manner and can be analyzed systematically to obtain much needed information. The information can be utilized for optimization purpose. A valid optimization strategy would permit the adjustment of those manipulable variables, which influence the objective.

The statistical techniques have been used to study the flotation of minerals, (Yalsin, 1999; Rao and Mohanty, 2002; Cilek and Yilmazer, 2003, Martinez et al., 2003) and coal (Rao et al., 1982; Mohanty and Honakar, 1999) but the interaction effect is interpreted by only a few (Rao et al., 1982) though these effects have important bearings on flotation of coal. The effect of collector and frother keeping one of them at constant are studied by several authors (Klimpel, 1988; Klimpel and Hansen, 1987). The plant performance has been predicted using multivariable statistical model (Lind et al., 2003). For the present work, coking coal fines constituting particles that cannot be floated to particles that can float without the aid of any reagent have been selected. The most widely used reagents of coal flotation namely hydrocarbon oil (kerosene), frother (MIBC) and rarely used a dispersant (sodium meta silicate) have been chosen for the study and attempt has been made to interpret their interaction effects.

2. Experimental

2.1. Material

Coking coal fines (−5 mm) generated at Bhelatand coking coal washery in Bihar, India, were collected for the purpose. The sample was sieved at 500 μm for the purpose of this experiment. The complete size distribution and ash for individual size fractions of the sample are presented in Table 1. The sample thus prepared on average contained 15.6% ash and 64.7% fixed carbon (Table 1). Kerosene oil and MIBC were used as collector and frother, respectively, and sodium (meta) silicate ($Na_2SiO_3 \cdot 9H_2O$), supplied by LOBA Chemie, India was also used as a dispersant.

2.2. Methods

A Denver D-12 sub-aeration flotation machine with a 1-l capacity cell was used for flotation studies. Coal sample (100 g) was mixed with 300 ml of water and conditioned in the flotation cell for 2 min.

Table 1
Characteristics of the coal sample used

(a) Size and ash distribution

Size, μm	Wt, %	Ash, %
−500+300	15.6	16.0
−300+150	17.9	19.0
−180+75	9.6	20.3
−75+45	24.9	12.7
−45	32.0	13.8
Head	100	15.4

(b) Proximate analysis of −500 μm coal

Details	Wt, %
Moisture	0.1
Volatiles	19.6
Ash	15.6
Fixed carbon	64.7