Application of hydrophobic and magnetic plastic particles for enhanced flotation recovery

Rick Q. Honaker *, Mehmet Saracoglu, Qingqing Huang

Department of Mining Engineering, University of Kentucky, 504 Rose Street, 230 Mining & Mineral Resources Bldg., Lexington, KY 40506-0107, USA

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ABSTRACT

The effect of hydrophobic and magnetic plastic particles having a contact angle of around 83° on flotation performance was evaluated using coal particles of varying degrees of floatability. The magnetic plastic material were recovered by a low intensity magnetic separator and recycled back to the flotation feed for re-use. Flotation rate tests conducted on coal using a conventional cell proved that combustible recovery and flotation rate were significantly enhanced with the addition of the plastic particles, especially for difficult-to-float coals, which was corroborated by flotation column tests. Carrying capacity and particle size-by-size flotation tests further showed that the magnetic plastic particles preferentially increased the recovery of coarse particles by as much as 35 absolute percentage points due to froth stabilization which reduced the selective detachment of coarse and/or weakly hydrophobic particles. The enhanced flotation recovery was attributed to the influence on liquid drainage rate in the froth zone, froth stability, bubble coalescence and flotation rates.

1. Introduction

Froth flotation is the most commonly used process to recover and upgrade ultrafine (<150 μm) material in the coal and minerals industries. It is well known that the froth flotation process consists of two separate and distinctly different zones, i.e., the collection zone and froth zone (Jameson et al., 1977; Yianatos et al., 1998; Finch and Dobby, 1991). The overall recovery is the result of the interaction between these two zones.

The separation of the valuable mineral from the non-valuable mineral components in the collection zone is based on differential flotation rates which are determined by critical parameters involving the processes of bubble-particle collision, attachment and detachment (Ahmed and Jameson, 1989). The flotation rate constant is also a function of the particle size in the flotation feed through the probabilities of collision, attachment and detachment, which can result in significantly different recovery values for a given residence time (Jowett, 1980; Yianatos et al., 2001; Jameson et al., 2007; Jameson, 2010; Kohmuench et al., 2010). Therefore, a narrow particle size range exists for optimum flotation performance from which a low and upper particle size limit is obtained for a given material. The lower particle size limit is based on

limited bubble-particle collisions while the upper limit results from bubble-particle detachment.

In the froth zone, froth stability which is impacted by bubble coalescence and water drainage has been shown to play a significant role in determining froth zone recovery and thus overall flotation recovery (Cho and Laskowski, 2002; Neethling and Cilliers, 2003; Tan et al., 2005a; Tan et al., 2005b; Cilliers, 2007; Farrokhpay, 2011). Water drainage from the thin film in the Plateau border surrounding a bubble causes film thinning and accelerates the approach of two air/liquid interfaces associated with interacting bubbles. Once the film thins to a certain critical thickness, bubble coalescence occurs which reduces the bubble surface area available for conveying hydrophobic particles through the froth phase and into the froth concentrate. If the total bubble surface flux exiting the flotation system is insufficient to allow all attached particles to report to the concentrate, relatively coarse and/or weakly hydrophobic particles are selectively detached and returned with the draining water to a lower point in the flotation cell (Honaker and Ozsever, 2003; Honaker et al., 2006).

For decades, research efforts have targeted methods that have the ability to enhance flotation performance including the addition of particles having a higher degree of hydrophobicity (Ata, 2012). Froth stability provided by the addition of more hydrophobic solid particles occurs due to added resistance to film drainage. Thus, froth stability benefits from an increase in the three-phase contact angle

* Corresponding author.
E-mail addresses: rick.honaker@uky.edu (R.Q. Honaker), msara2@uky.edu (M. Saracoglu), qhu223@g.uky.edu (Q. Huang).

formed between the solid surface, water and air interfaces. Previous investigations suggest that hydrophobic particles with contact angles between 65° and 90° enhance froth stability and those with contact angles greater than 90° destabilize the froth (Dippenaar, 1982a, 1982b; Johansson and Pug, 1992; Garrett, 1993). In the latter case, the particles begin to work as bridges between bubbles that eventually are drawn together by the highly attractive hydrophobic force (Yoon and Mao, 1996; Yoon and Aksoy, 1999; Wang and Yoon, 2005). As a result, the water film thins and bubble coalescence occurs. However, in the case of partial wetting, the particles trap the liquid and make the film more stable (Ip et al., 1999). Large concentrations of small hydrophobic particles stabilize the froth through a closely packed monolayer bed that prevents the particles from streaming out of the film and keeps the interfaces from contacting each other for film rupture (Dippenaar, 1982a). Schwarz and Grano (2005) further corroborated the improvement in froth stability resulting from particles having intermediate hydrophobicity while the addition of hydrophilic particles imposes minimal effect and super hydrophobic particles destabilize the froth. The degree of these effects is also impacted by the particle size distribution of the particles (Dippenaar, 1982a; Johansson and Pugh; 1992; Rahman et al. 2012). The presence of hydrophobic particles significantly increases the viscosity of the thin water film around a bubble, which in turn, slows the drainage process (Jiang, 1998; Ata et al., 2003).

The ability to stabilize the froth phase by the addition of intermediate hydrophobic nanoparticles was studied in detail by Bournival et al. (2014). The investigation found that the nanoparticle addition increased the recovery of weakly hydrophobic particles having an 80% passing size of 230 μm due to the positive impact on froth stability. In an attempt to apply this concept to benefit commercial flotation systems, moderately hydrophobic particles that can be recovered and recycled using a low intensity magnetic separator has been investigated (Honaker and Tao, 2009). The subject of this publication is the use of a recoverable hydrophobic material having a contact angle of 83° to improve recovery from both conventional flotation cells and flotation columns. The effect on flotation recovery and selectivity was evaluated which included an assessment of the impact on the upper and lower particle size limits.

2. Experimental

2.1. Coal sample

Two different bituminous coal samples were used for the investigation which included representative samples collected from operations treating Pittsburgh No. 8 and Coalburg seam coals. The Pittsburgh No. 8 coal was easy-to-float and contained a relatively high amount of coal pyrite while the Coalburg coal had a relatively high content of middling (weakly hydrophobic) particles of around 15% by weight. Representative samples of Pittsburgh and Coalburg coal were collected from operating coal preparation plants in Blacksville and Logan W.V. (USA), respectively. Each coal type was crushed using a laboratory jaw crusher to reduce the particle size to below 1.27 cm. The crushed coal was air dried for 24 h to remove excess surface moisture. Afterward, the sample was cone-and-quartered followed by riffling to obtain homogenous representative coal samples. The split samples were placed in air tight sample bags and stored in a drum that was flushed with nitrogen. For each flotation test, a representative sample lot from the drum was pulverized to a particle size finer than 177 μm. One of the representative lots for each coal source was used to characterize the material and the results are provided in Table 1.

Table 1
Proximate analyses for Pittsburgh No. 8 and Coalburg coal samples.

| Coal characterization	Pittsburgh No. 8	Coalburg
Ash content (%)	16.3	36.12
Total sulfur (%)	3.07	0.68
Volatile matter (%)	34.11	23.21
Calorific value (kJ/kg)	29,219	21,220
Surface moisture (%)	0.66	2.40

2.2. Magnetic plastic material

The magnetic plastic material is commercially known as Poly-Mag™ Black Pellet (PMBP) which is composed of about 70% magnetite (Fe_3O_4) and 30% ethylene/ethyl acrylate (EEA). EEA solids are known to be non-porous and, as such, minimizes available surface area for collector and frother adsorption. The material was provided by Eriez Manufacturing Company. The presence of magnetite in the material provided the ability to recover the plastic particles using a magnetic separator. The EEA coating material is a copolymer resin, which consists of ethylene (the simplest alkene) and ethyl acrylate monomers (ester of ethanol and acrylic acid), and is currently used in the preparation of numerous polymers.

The morphology of the magnetic plastic particles was studied using a Hitachi S-2700-Scanning Electron Microscope at 500 μm optical resolution after being pulverized in a hammer mill to obtain the desirable particle size distribution for use in the flotation process. The scanning electron micrograph in Fig. 1 shows individual particles of the PolyMag™ material. Some of the large particles have distinct, circular/elliptical shapes while the smaller particles appear to be non-spherical. Based on energy dispersive X-ray analyses and given the relative particle size difference between the plastic particles (47% > 150 μm) and the magnetite particles (95% < 45 μm), the particles were well coated with the EEA copolymer resin which was the source of the surface hydrophobicity.

2.3. Particle size analysis

Representative samples of both coal sources and the magnetic plastic material were prepared for the flotation tests using a laboratory hammer mill to reduce the particle size to finer than 177 μm. The magnetic plastic material, PMPB, was received as dry pellets with a particle size of 100% minus 6.35 mm. The pulver-
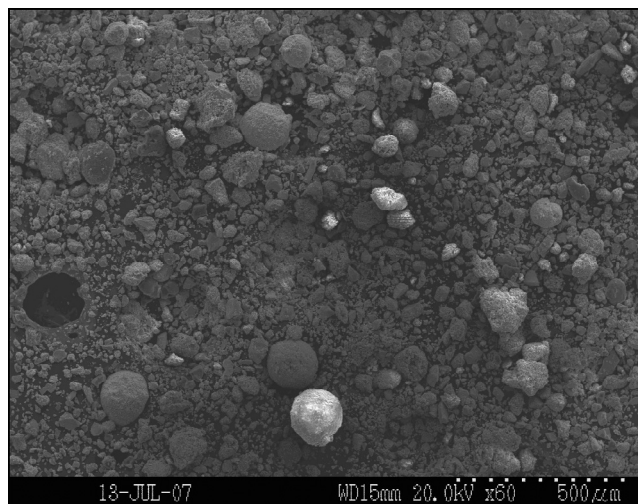
Fig. 1. SEM micrograph of individual magnetic plastic particles after pulverization in a hammer mill.