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Fine coal beneficiation by column flotation

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ABSTRACT

The amenability of beneficiating a fine hard coal from Hwa-Sun coal mine using column flotation has been studied using a *CoalPro* flotation column developed by Canadian Process Technologies (CPT). After initial testwork using a batch flotation cell to determine the optimal flotation conditions, tests were carried out to compare its performance with the column. The results showed that the performance of the column was far superior to that of the conventional cell owing to the large fines content present in the coal. It was established that a stable froth column of 40 cm in height and a suitable balance between froth and collection zone could be maintained at 1.0 cm/s superficial gas rate. A suitable reagent scheme and the optimal operating conditions that minimized adverse effects generally encountered in treating fine coal, such as gangue entrainment, have been identified. An increase in water recovery significantly decreased ash rejection implying entrainment of fine ash particles. Column flotation is capable of producing an acceptable clean coal concentrate of 85% combustible recovery with 81% ash rejection at a maximum separation efficiency of 62%, compared to conventional flotation which has 70% recovery with 70% ash rejection at an efficiency of 42%.

1. Introduction

Coal is one of the main fossil fuels that supplies energy of up to 30% worldwide and has been widely perceived as a strategic energy source particularly in countries with poor energy resources, due to rising oil and gas prices. Utilization of coal for energy production requires the removal of ash as well as hazardous materials such as SO_x and NO_x [1]. In order to clean low rank coal physical separation techniques, such as gravity separation, electrostatic separation and froth flotation have been used extensively owing to their low cost. Of these, froth flotation is the most common technology used for fine coal beneficiation.

Froth flotation exploits the differences in surface hydrophobicity of the different constituent minerals and selectively separates the valuable minerals from gangue by attaching them to air bubbles and recovering them from the mineral laden froth [2]. Conventional flotation that uses mechanical cells has been known to be ineffective in processing fine coal mainly due to entrainment of fine gangue minerals in the froth that requires complex circuit arrangements that incorporate several cleaner stages [3]. In contrast, column flotation has been effective in cleaning fine coal as it has many advantages over conventional flotation owing to its ability to effectively reduce entrainment of fine gangue minerals due to less turbulence in the pulp, having a deep froth bed and using wash water to drain back the entrained gangue. In addition, column flotation is preferred due to its simpler construction, convenience in incorporating automatic control, as well as a having single-stage system which embodies rougher, cleaner, and scavenger [4,5]. Several studies also have emphasized that column flotation is superior to mechanical flotation in handling both coarse and fine fractions and gives a higher recovery with lower ash content [3,6–9].

In this study, an attempt has been made to identify the most significant parameters in designing flotation columns for processing a finely-sized low rank coal including water recovery that influences fine gangue entrainment.

2. Previous work

The working mechanism of a typical flotation column and its important process variables are shown schematically in Fig. 1.

Several studies on column flotation have focused on the froth stability and the pulp level, entrainment of fine particles, flotation rate, product grade/recovery relationships and carrying capacity. Goodall and O'conner [10] observed that decreasing air rate and increasing frother concentration reduce entrainment and produce stable froth together with small bubbles in lab-scale column flotation.

Bias rate (J_b) which is the net flow of liquid down the froth column is related to the wash water rate and is of critical importance to the performance of the column. At high values it reduces the carrying capacity and at low rates it reduces grade. Thus, Finch and Dobby have recommended that J_b should be between 0 and 0.1 cm/s to reduce carrying capacity [11]. However, other researchers have recommended values between 0.1 and 0.4 cm/s in order to reduce gangue entrainment and achieve acceptable product grades [12,13]. Entrainment is a characteristic feature

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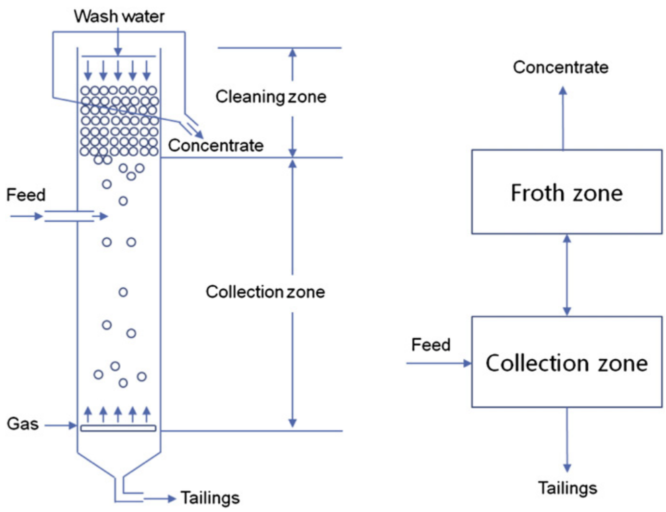

Fig. 1. Schematic diagram of flotation column.

of fine particle processing and is non-selective and bears no distinction between hydrophobic or hydrophilic particles [14]. The results of Kirjavainen [15] indicated that the entrainment of hydrophilic particles to the froth product is actually a statistical phenomenon in flotation tests using −45 μm quartz. Tao et al. [16] reported that in coal flotation, the presence of raw coal fraction between 30 and 150 μm stabilizes froth but that less than 30 μm destabilizes froth. Also, contact angles in excess of 90° have a tendency to destabilize the froth [16]. At high frother concentrations, the thickness of the bubble walls increase leading to lower bubble coalescence and thus, increases bubble stability [10]. The entrainment of particles in flotation is closely related to the water recovery [14]. Smith and Warren [17] have shown that entrainment becomes significant for particles smaller than about 30 μm, and it is proportional to the recovery of water into the froth products.

On the other hand, understanding and implementation of column flotation have undergone a rapid growth in relation to column design, construction, air sparging and operation since 1990s [11]. In particular, the air sparging system which generates small bubbles is an essential technology to achieve a higher flotation rate. The types of sparger designs include 1) Porous media that uses pierced plastic or fabric such as filter cloth [12], 2) Static shear contacting devices that use metal mesh packing to break up the gas stream into bubbles [18], in-line static mixers [13] or cyclones with vertical baffle, 3) Jetting devices which inject gas stream from an orifice into the slurry [19,20], and their improved designs such as slamjet or cavitation. In the coal industry, porous media spargers are still being used for basic laboratory studies but are no longer commonly used in commercial plants. Their disadvantage being the fact that the column must be shut down and drained prior to assessing or replacing sparger units, whereas both static shearing and jetting devices can be accessed more easily [21]. Main features of the more advanced sparger systems such as the microcel sparger system (Microcel™ column) are non-plugging ability, externally mounted for easy maintenance and also it can produce smaller bubbles (0.1 to 0.4 mm), which provide a higher flotation rate. It can also achieve a higher degree of turbulence inside the static mixer to produce smaller bubbles [13]. It has found wide applications in the coal industry in plants such as Alpha Inc. (Middle Fork etc., USA), Horizon Ltd. (Marrowbone, USA), and BHP (Peak downs and Saraji, Australia) [22].

Other commonly used type of sparger is the jetting type devices developed by the U.S. Bureau of Mines but it has been plagued with maintenance problems due to plugging of the orifices [23]. Recently, Eriez and Canadian Process Technologies (CPT) have developed CoalPro column flotation cell, which is equipped with *Slamjet* sparger that generates smaller bubbles using an air-lance and also Cavitation-Tube sparger using cavitation phenomena occurring when the slurry (pulp and compressed) air travels at high velocity through an hour-glass shaped tube [24]. CPT flotation columns have gravity-flow wash water system, multi-point feed distribution, internal product launders and self-closing sparger systems. Especially, the advantages of CPT spargers eliminate back-flow and plugging owing to a self-closing system and also capable of being mounted outside the column to simplify inspection and replacement [24]. Hence Canadian Process Technologies (CPT) CoalPro flotation column has been installed at over 500 diverse plants and extensively released in the world [4,24].

In this work, flotation tests on a low rank anthracitic hard coal from Hwa-Sun coal mine were carried out using lab scale CPT Coalpro column. Particularly, this study was focused on investigating variables such as superficial air rate, superficial wash water rate, feed solids concentration and several chemical reagents that affect column flotation with a view in identifying important variables for plant design.

3. Experimental

3.1. Materials

Coal sample (anthracite) used in this study was obtained from Hwa-Sun Coal Mine in South Korea. It is a low rank coal which was rejected as waste from the main processing plant. On analysis it was revealed that the ash in this coal could be liberated at about 150 μm size. Thus it was decided to grind the raw coal to this size and test the amenability of removing the ash by flotation.

3.2. Equipments and procedures

Preliminary tests to determine the effective reagent combination for flotation of this coal were carried out using a laboratory Denver sub-A batch flotation machine with 4 L cell. The minus 150 μm fraction was fed into flotation cell at 20% solids by mass and agitated for 5 min. The reagents tested were: collectors (kerosene and a patented collector developed for coal, DMU-101), frothers (MIBC, Dowfroth 250, Aerofroth 65 and pine oil) and depressants (Sodium metaphosphate (SMP) and Sodium silicate). These preliminary tests revealed that the optimal combination was DMU-101, MIBC and SMP.

The laboratory CPT CoalPro column flotation system used is shown in Fig. 2. Features of this column are: 1) height and diameter of column; 1500 mm and 55 mm, 2) Sparger; porous HDPE or optional cavitation tube and 3) automatic control for level, sparger air and wash water. The column's upper section consists of wash water distributor, froth collection launder and feeder while the lower section houses the sparger (bubble generator) and tailings outlet. The feed slurry inlet is at a point of 1/3 of column height from the top. The wash water was fed at the top of the column while the tailings were collected at the bottom of the column. The concentrate and tailings products were collected and dried in the dryer at 105 °C for 24 h. The contents of ash, fixed carbon, volatile materials and moisture were measured using proximate analyzer (TGA601, LECO Ltd., USA).

The composition of samples of coal and ash was analyzed using SEM, XRD and XRF techniques.

The following procedures were followed in the preparation of samples for these analyses.

3.2.1. Scanning electron microscopic analysis

A field emission-scanning electron microscope (FE-SEM, S-4800, Hitachi, Japan) equipped with an energy dispersive X-ray spectrometer (EDS, Link Isis 3.0, Oxford Instruments plc, U.K.) was used for this analysis of coal samples. Generally when using this equipment, carbon coating of the sample surface is required in order to make it conductive. However since the sample contains carbon a platinum coating was applied instead. First, each coal product sample was mixed with a volatile solvent alcohol (ethanol), dispersed and cleaned in an ultrasonic bath. The sample was then placed on a stub over a thin layer of silver (Ag)