International Journal of Mining Science and Technology 27 (2017) 285–292

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Evaluation of graphite depressants in a poly-metallic sulfide flotation circuit

Nikhil Gupta

Department of Mining and Minerals Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA

ARTICLE INFO

Article history:
Received 5 September 2015
Received in revised form 22 March 2016
Accepted 8 July 2016
Available online 31 January 2017

Keywords:
Graphite depressants
Sulfide flotation
Dyes
Starch
Bagasse
Hydrophobic impurities

ABSTRACT

Synthetic dyes are commonly used for graphite depression in poly-metallic flotation circuits; however, these dyes can be very expensive. The aim of this study is to evaluate performance of certain low-cost alternative depressants for a complex lead-zinc (Pb-Zn) ore rich in graphite (Gr-C) on a conventional mini pilot-scale flotation circuit. The reagents used were commercial and industrial grade starch; agro-based waste-sugarcane bagasse and charred (burnt) bagasse powder. The primary evaluation criteria were quality (grades) of lead and zinc concentrates, their recoveries (%), and graphite rejection (%) in the tails. Benchmark tests using nigrosine as graphite depressant showed 94.3% rejection of Gr-C. The results with commercial starch were found as effective with 93.8% graphite rejection. Furthermore, bagasse powder showed potential in improving product quality (36.4% and 65.6% Pb grade and recovery) with an intermediate effectiveness in graphite rejection (85.6%). The order of effectiveness in Gr-C rejection follows nigrosine ≈ commercial starch > bagasse > industrial starch > charred bagasse. In addition, the effect these depressants on silver (byproduct) grade and recovery was also investigated.

1. Introduction

Rampura-Agucha (RAM) is one of the world's largest zinc mines in India. Typical RAM ores are complex multi-metallic sulfides hosted in Graphite-Mica-Schist (GMS) type rock. The ore carry low-grade lead (PbS 1–3%), high-grade zinc (ZnS 10–13%), and other critical minerals such as silver, cadmium, nickel, cobalt and molybdenum that can be found in trace amounts in combination with impurities such as, pyrite, pyrrhotite, and graphitic-carbon [1]. The predominant rock forming minerals are quartz, carbonates (calcite, dolomite and witherite), barites amphibole, mica, pyroxene talc, and other silicate gangue [2]. The separation of valuable minerals from such ores has attracted much interest in last three decades because it has become evident that the conventional flotation technologies that have worked well on simple ores are not able to produce consistently efficient separations for these types of complex ores [3–5].

The GMS type ore at RAM contains significant amount of recoverable lead and zinc, but also a high percentage of graphite (up to 12% by weight). The mineral assemblage characteristics of these deposits, as shown in Fig. 1, are made up of a few well-crystallized phases of simple compositions. Galena occurs with sphalerite and pyrite as coarse-grained intergrowths and platy inclusions along the cleavages of mica and graphite, and silicate gangue. Both galena and sphalerite layers are entrapped within cleavages of graphite forming a sandwich like texture. Inclusions of assorted sized shards of graphite can be noticed within galena in Fig. 1.

The separation strategy for this complex lead-zinc ore involves comminution to very fine sizes to achieve liberation, followed by differential flotation of galena and sphalerite. Hydrophobic impurities such as, graphitic-carbon (Gr-C), mica, talc, are flaky and float naturally that can get carried with froth concentrate. Flake graphite is pressumed to form when organic matter in sediments metamorphosed. Higher concentration of graphite in ore can smear other hydrophillic impurities and make them to float as well. The presence of this hydrophobic gangue can create deterioration in the quality of valuable minerals that affect the downstream mineral extraction processes. It is evident that presence of graphite in lead concentrate results in poor metallurgical yield, reduction in strength of sinters, difficulty to control temperature during roasting, and difficulty in sulfur removal [3,6].

In previous years, methods such as pre-graphite flotation and reverse flotation have been tested on a laboratory-scale. In former, the finely ground ore slurry is processed with flotation to remove hydrophobic graphite prior to treat in a lead-zinc flotation circuit. While in latter method, galena is first depressed with potassium dichromate followed by flotation of graphite. The studies reported

E-mail address: nikhilng@vt.edu

http://dx.doi.org/10.1016/j.ijmst.2017.01.008
2095-2686/

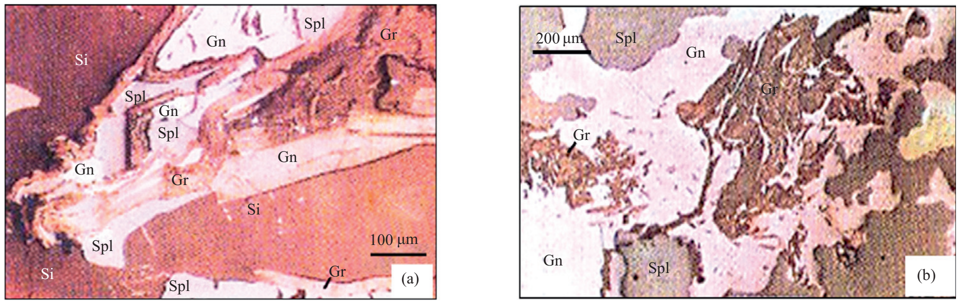

Fig. 1. Galena (Gn) and Sphalerite (Spl) sandwiched between Graphite (Gr) laths and silicates (Si) (left) and inclusions of assorted sized shards of Graphite (Gr) within Galena (Gn) [courtesy: HZL] (right).

that due to the excessive loss of valuable minerals and water contamination from dichromate, these methods could not be incorporated in processing plants [3]. In some other studies, gravity separation techniques such as Wilfley Table and Multi-gravity Separator (MGS) were implemented on galena rougher concentrate and showed graphite rejection as high as 93.8% [7,8].

Alternatively, graphite depressing reagents can be used during grinding and pre-conditioning steps of flotation. Synthetic dyes for graphite depression have been found somewhat effective while producing better quality product [9,10]. These studies showed graphite content less than 5% and 2% in lead and zinc concentrate, respectively.

In general, the basic purpose of depressants is to improve the selectivity of valuable minerals by preventing flotation of unwanted minerals. These reagents can prevent flotation by acting on a mineral surface or by reacting with the collector (or activator) in bulk solution. In general, each depressant is specific to a mineral-collector-activator system [11] and the function of depressant is just the opposite to that of collector. A depressant attaches to the surface of floatable unwanted impurities and render the particles strongly hydrophilic and thereby acting as a barrier to collector adsorption and air-bubble attachment [12]. Therefore, a depressant must have functional groups that exhibit a preferential attraction to the gangue mineral surfaces, and on the other hand, these molecules should not have functional groups that can compete with the collector for adsorption on the surface of the valuable minerals.

Synthetic dyes are expensive reagent that can directly impact the operation and production cost. Therefore, it is important to find an alternative depressant that should be at least equally effective, and easily available at a lower cost. The most commonly encountered functional groups on polymeric depressants are hydroxyl carboxylate, sulfonate, and amine [13]. Since each of these functional groups exhibits varying degree of affinity to different minerals, it is critical that the proper type be selected for each situation [14]. A general rule to follow is to consider what would be good collector to the particular mineral that needs to be depressed, and then select a depressant that includes the same functionality as the collector but replacing hydrophobe with a hydrophile molecule [15].

In many cases, organic macromolecular depressants, such as starch, dextrin, dyes, have been proven effective in mineral beneficiation for depressing hydrophobic undesirable minerals [16–25]. Sometimes the use of such depressants is almost indispensable. Other studies evaluated monomeric poly-hydroxyl reagents such as glycol, sucrose, but were proven ineffective as hydrophobic depressants [4,26,27]. Furthermore, studies have concluded that the adsorption mechanism of organic depressants has not been well understood. It is presumed that some of the polar groups of these compounds form hydrogen bond with the hydroxyl group at the surface of the hydrated silicates, leaving more polar groups oriented towards the solution thus make the system hydrophilic [14,26]. In the case of monomeric poly-hydroxyl reagents the adsorption and desorption of functional groups on the mineral surface exists in a dynamic equilibrium, and water always competes strongly with the mineral surface for the hydroxyl groups. Therefore, due to the presence of limited number of available functional groups, the monomeric species may not be able to maintain an adequate association with the mineral particles and unable to impart enough hydrophilicity for adsorption. On the other hand, the polymeric molecules have numerous hydroxyl groups distributed throughout the structure to maintain the required dynamic attachment, and thus exhibit an adequate depression to a hydrophobic gangue particle [14].

Considering that the factors involved in controlling the depressant adsorption on this complex multi-metallic are not very well understood, this communication focuses only on a qualitative evaluation. For the purpose, commercial grade and industrial grade starches were tested. Commercial grade starches are commonly used in food industry and are environmentally friendly. Industrial grade starch applications include textile and paper industry. In addition, agro-based sugarcane waste material, i.e., dried bagasse powder was also evaluated. Lastly, charred bagasse powder was evaluated as a graphite depressant. Bagasse and charred bagasse has never been investigated earlier as hydrophobic mineral depressants. Lead grade and graphite content in lead concentrates, lead recovery, and graphite rejection in the final tailings relative to the feed is used as parameters to evaluate performance of these alternative graphite depressants.

2. Theory

The distinct nature of macromolecular poly-hydroxyls includes a long hydrocarbon chain for adsorption at hydrophobic mineral surfaces, a large number of well distributed hydroxyl groups (—OH), and strong nature of polar groups to combine with water molecules [12]. Presumably, the two unique capabilities of the hydroxyl groups on these organic macromolecules that make them effective depressant are first, they provide strong hydrophobicity as well as fairly good affinity to gangue minerals. Second, they are not nearly as surface active as most charged collector adsorbs, and therefore, compete less effectively for the active sites on the surface of the valuables [27].

Graphite composed of neutral carbon atoms that are not able to form hydrogen bond with water molecule, therefore, is naturally hydrophobic. Starches are the group of polysaccharides that comprise glucopyranose units joined together by glucosidric linkages. These linkages can be linear, unbranched, moderately or highly branched, as well as flexible or rigid. Starches have been found effective in some cases in depressing hydrophobic impurities [14,19,28–30] because the hydroxyl groups can form hydrogen bonds with water, while other part of the starch molecule adsorbs