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Investigation of the effect of mineralogy as rate-limiting factors in large particle leaching

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ABSTRACT

Although heap leaching is by now well established in the mining industry, the process remains limited by low recoveries with different rate-limiting factors that are not clearly understood. In this study, three large particle size classes (+19/−25, +9.5/−16, +4.75/−5 mm) were prepared from a sphalerite ore by two different methods of comminution (HPGR and cone crusher). The particles were then packed into leach reactors that were operated continuously for 11 months with well-mixed internal circulation of the leach solution. Characterization of the residue of the leach reactors indicated that there are areas within the ore particles where although sphalerite grains are accessible to the solution, they remain unreacted. X-ray tomography and QEMSCAN® analysis of the selected samples before, during and after leaching, showed increased leaching of sphalerite grains associated with pyrite due to galvanic interactions. Mineral chemistry (Fe, Mn content of sphalerite) and jarosite precipitation were also investigated as factors influencing sphalerite leaching.

1. Introduction

Although heap leaching is by now well established in the mining industry, the process remains limited by low recoveries (up to 60–70%), long extraction times (over a 1–2 years period), and high operating costs, especially in terms of acid consumption. As the technology becomes more and more adopted, it is increasingly clear that the successful application of heap leaching technology will ultimately depend on having a comprehensive understanding of the underlying fundamental processes for optimization to take place (Acevedo, 2002; Dreisinger, 2006; Mellado et al., 2009).

Ores are placed in heaps in a relatively coarse particle size distribution, reaching up to 25 mm top size for crushed and agglomerated ores and as much as 500 mm for ROM ores in dump leaching (Watling, 2006). Leaching from large ore particles is, however, poorly understood and commonly assumed to follow shrinking core type behavior. A conventional shrinking core approach would work only for gangue particles that are homogeneously porous and have mineral grains well distributed throughout (Liddell, 2005; Veglio et al., 2001). In fact, there is a dearth of literature sources that offer any evidence for the validity of this assumption in the given context (Ghorbani et al., 2011a). Recent experimental evidence suggests that leaching from large particles occurs only at the surface and in sub-surface regions, which are accessible from the surface by cracks and pores (Malmström et al., 2008; Sracek et al., 2006; Strömberg and Banwart, 1999; Ghorbani et al., 2011b). This would suggest that leaching behavior might be closely related to the method by which the ore has been crushed prior to leaching (Rawlings et al., 1999; Rawlings, 2005; Watling, 2006).

The relatively coarse particle size distribution is one of the unique features of heaps that poses a major technical challenge; namely to suitably expose the mineral grains within the ore to the lixiviant, be it acid, ferric ions or bacteria and oxygen. One possible approach to improving recovery in the heap is to introduce fractures into large ore particles, so increasing the surface area available for lixiviant attack. Extensive cracking can be induced in a number of ways; one of which is through compression or particle bed breakage with the High-pressure grinding rolls (HPGRs).

This paper forms part of a larger study aimed at understanding the mechanisms taking place during large particle leaching that has been conducted on a sphalerite ore. The initial ore sample was prepared using cone crusher and HPGR. Comminution results are reported in (Ghorbani et al., 2011c). Initial particle characterization using mineralogy and X-ray computed tomography (X-ray CT) consistently identified the prevalence of micro-cracks and higher porosity for particles prepared by compression breakage (HPGR) as compared to conventional crushing by impact breakage (Ghorbani et al., 2011d). In this study, three large particle size classes (+23/−25, +14/−16, +5.25/−6.75 mm) were prepared from a

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sphalerite ore from the Northern Cape, South Africa, by two different methods of comminution (HPGR and cone crusher) and packed into leach reactors, which were operated continuously and well mixed through internal circulation of the leach solution for 11 months.

A comparison of the effect of the different comminution devices on metal extraction indicated that HPGR crushed ore leached more rapidly in all particle size classes and showed 10–15% additional zinc leach extraction (Fig. 1), since the presence of micro-cracks provides an additional surface-front of target mineral grains for attack by the leaching solution, and a higher prevalence of attachment sites for microorganisms for regeneration of ferrous to ferric iron as leach reagent (Ghorbani et al., 2012e).

Characterization of the residue of the leach reactors indicated that there are areas within the ore particles where although sphalerite grains are accessible to the solution, they remain unreacted. These results indicate that although accessibility to the reagent is necessary, a variety of other rate-limiting factors in large particle leaching can hamper or prevent leaching of an ore.

The objective of this study is to investigate the role of mineralogy as a rate-limiting factor in large particle leaching. This is done using 3D particle characterization from X-ray CT in combination with detailed 2D mineralogical characterization (QESCAN, EMPA, SEM/EDS). The focus areas in this study are the effect of mineral chemistry and impurity content, mineral association and mineral precipitation on the rate of sphalerite leaching.

2. Experimental

2.1. Sample preparation

A bulk sample of sphalerite ore was obtained from the Gamsberg Zinc mine in the Northern Cape Province, South Africa. The sample, after primary crushing by jaw crusher, was split and prepared into 250 kg bags for further crushing by either HPGR or cone crusher at Mintek in Randburg, South Africa. HPGR test work was conducted using a Köppern unit equipped with 1 m diameter rolls and was fully instrumented to control and record hydraulic and nitrogen pressures and throughput. The unit was fitted with profiled hexadur. Further details of comminution in terms of HPGR pressure settings, energy and particles size distribution (PSD) are given in Ghorbani et al. (2012c). The same top size was fed to the cone crusher and crushed down to −25 mm. Products from the cone crusher and HPGR were then screened into five size fractions (+23/−25, +16/−23, +14/−16, +6.75/−14, +5.25/−6.75 mm). In this study, subsamples from the (+19/−25, +9.5/−16, +5.25/−6.75 mm) size fractions were used for the leach experiments.

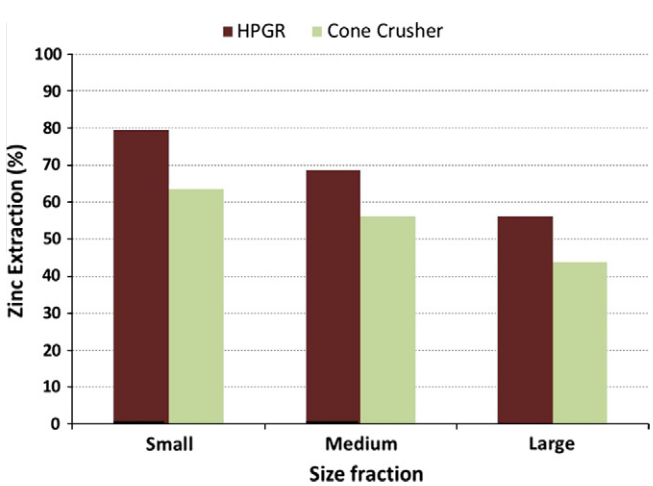

Fig. 1. Leachability of zinc for different particle size classes, HPGR-95 bar product versus cone crusher.

2.2. Leach experiments

Selected sub-samples as summarized in Table 1 were packed into custom designed leach reactors in which the leach solution was continuously circulated around stacked baskets containing ore particles. The particles were fully immersed in leach solution and the reactor was operated in continuous mode for 11 months. Full details of reactor operation and chemical dynamics during leaching (pH, redox potential, Fe^{3+} and Fe^{2+} concentration as well as total Fe, Zn, Mg, Al and planktonic cell concentration) in the effluent solution are given in Ghorbani et al. (2012e).

The reactors were stopped from time to time to investigate the progress of leaching by analyzing X-ray CT images of individual tagged particles. After X-ray CT analysis, the tagged particles were returned to the reactors for leaching. A further sub-set of particles was also removed from the columns at each reactor stoppage to further validate the non-destructive X-ray CT analysis with those measurements obtained using more traditional, although destructive techniques such as SEM/EDS, QEMSCAN® and EMPA.

2.3. Mineralogical analysis

X-ray CT was used for 3-D characterization of the sphalerite particles prior to leaching, during the course of the leach experiments and after leaching. The non-destructive nature of this technique allowed a virtual "in situ" characterization of the ore particles during leaching. During the stoppage of the leach reactors, individual tagged particles (eight particles for small, four for medium and two for large size fraction) were analyzed using X-ray CT.

Selected particles were washed using distilled water and dried to avoid the blocking of the cracks and micro-cracks with any precipitates that may have formed during the course of the leach experiments.

An HMXST CT scanner at X-Sight X-ray Services in Stellenbosch, South Africa, with 225 kV X-ray source, 3 μm resolution reflection target, and interchangeable Nano-tech 1 μm transmission target was used. The mineralogy of the measurements was calibrated using the dual energy method. The 3D volumes of the individual tagged particles were interrogated using the VG Studio Max software. Full details of the X-ray CT measurement conditions and data processing are summarized in Ghorbani et al. (2011d).

QEMSCAN® was used to determine the bulk mineralogy of the ore sample (prior to and post leaching) as well as monitor the changes in mineralogy over the 11 months experiment. The QEMSCAN® unit used in this study was located at the University of Cape Town, and is based on a LEO SEM platform equipped with two Bruker 4010 SDD detectors. Operating conditions were set at 25 kV and 5 nÅ beam current. Measurements of the bulk mineralogy were obtained using the bulk mineralogical analysis (BMA) routine on a series of sized samples (+120; +90; +63; +38; −38) μm. Samples were dry sized to avoid the dissolution of any soluble precipitates that may have formed during the course of the leach experiments. Individual ore particles (5–25 mm) that were sampled at each of the reactor stoppages were analyzed using the Field Image analysis routine. Ore samples were mounted in epoxy resin and prepared into polished 30 mm diameter mounts. Pixel spacing between 3 and 5 μm was used for BMA analysis (depending on the size fraction) and a pixel spacing of 20 μm was used for the field image analysis. The results from QEMSCAN® were validated by comparison with XRF data and QXRD data.