

Mössbauer analysis of BIOX treatment of ores at Wiluna gold mine, Western Australia

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Abstract Mössbauer phase analysis of samples taken from nine stages of the bacterial oxidation processing of gold ore at the Wiluna Gold Mine followed the transformation of the arsenopyrite/pyrite minerals. The principal end-stage phases were szomolnokite, ferric oxyhydroxides, ferric arsenates, jarosite and incompletely transformed pyrite, with higher hydrates of ferrous sulphate being created and then dehydrating to szomolnokite during the processing.

Keywords Gold extraction · Refractory ore · Bacterial oxidation · BIOX · Pyrite · Arsenopyrite · Ferrous sulphates · Ferric arsenates · Ferric oxyhydroxides

1 Introduction

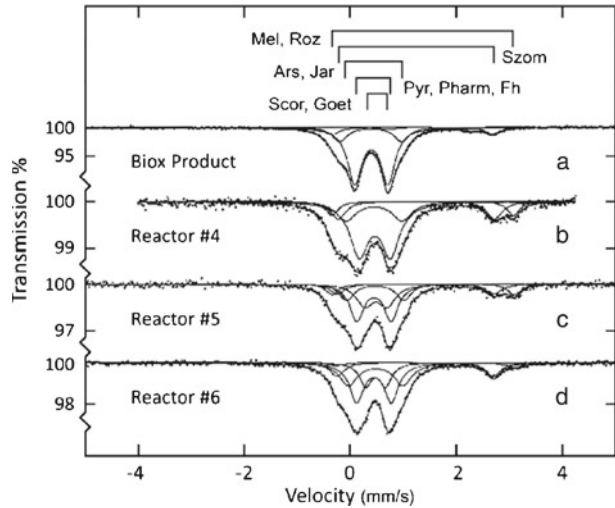
The treatment of refractory gold ores has long been a problem for the gold mining industry. The gold in these sulphide ores is incorporated in the structure of the minerals and is not accessible for leaching by cyanide or other leachants. The traditional treatments have been by roasting, pressure oxidation or nitric acid leaching.

A more recent technique [1], originally developed by Gencor Process Research in Johannesburg under the name BIOX[®], and now owned by Biomin Technologies SA, a subsidiary of Gold Fields Ltd, uses three natural strains of bacteria to oxidize the sulphidic ores. The sulphur and iron-loving bacteria break down the ore matrix in a series of stirred reactors. Maintenance of the optimum conditions requires control of the temperature and pH, the input of air to aid the oxidation, and carbon dioxide,

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Fig. 1 ^{57}Fe Mössbauer spectra of selected samples taken at 78 K



nitrogen, phosphorus and potassium to assist bacteria growth. The residence time is typically 4–6 days. The optimum conditions must be determined for each ore body and the large number of variables makes this difficult. Literature analyses of the process are typically in terms of reactions between ion species, with little prediction or real analyses of the final mineral products, which is essential for understanding the later environmental effects. Mössbauer spectroscopy was used to analyse the types and concentrations of the iron-containing compounds under operating conditions at nine points in the BIOX[®] plant at the Wiluna Mine in central Western Australia.

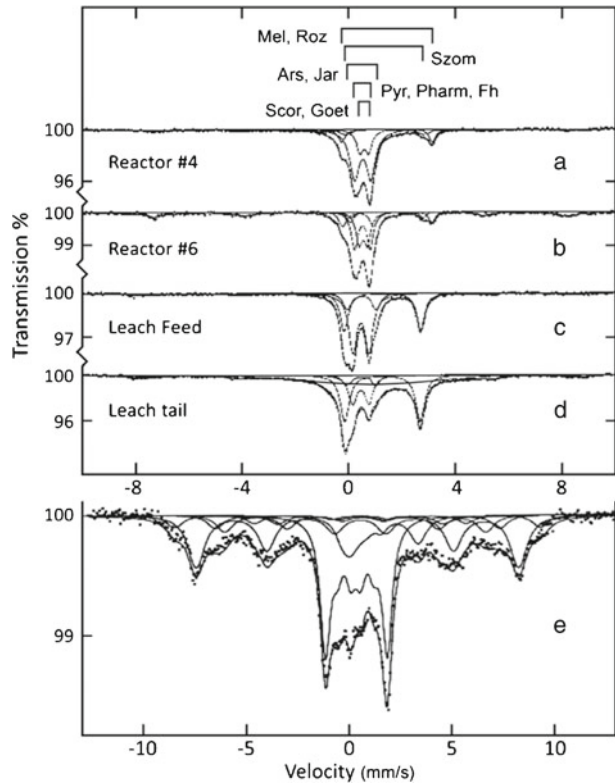
2 Samples

The BIOX[®] plant takes a continuous feed of a flotation concentrate slurry which initially goes to three stirred, primary reactors in parallel, followed by another three reactors in series. The output of the final reactor goes through a wash and thickening process from which it is separated into the leach feed for cyanide extraction of the gold, and the tails. The analysis covers samples taken from each of these nine parts in the process. Spectra were taken at room temperature, 78 K and 5 K, with some spectra also taken in applied magnetic fields to aid identification of poorly crystalline species.

3 Results and analysis

The 78 K spectrum of the input feed (Fig. 1a) is dominated by the doublets of pyrite, FeS_2 , and arsenopyrite, FeAsS , with a smaller contribution from szomolnokite, $\text{FeSO}_4 \cdot \text{H}_2\text{O}$. The fraction of arsenopyrite approximately halved after the parallel primary reactors, in agreement with the known fact that the bacteria attack arsenopyrite preferentially. As the reaction proceeded, subsequent spectra became difficult to analyze because of the similar parameters of the different possible species,

Fig. 2 ^{57}Fe Mössbauer spectra of selected samples taken at 5 K, (e) reactor #6 sample in magnetic field of 9 T



e.g. at room temperature or when SPM at low temperature (scorodite, goethite, pyrite, ferrihydrite, pharmacosiderite and schwertmannite, $QS = 0.4\text{--}0.7$ mm/s) and (arsenopyrite and jarosite, $QS = 0.98\text{--}1.1$ mm/s), while in spectra at 5 K (goethite and scorodite, $B = 50.6\text{--}52$ T), (ferrihydrite and aluminous or poorly crystalline goethite, $B = 47\text{--}50$ T) and (schwertmannite, pharmacosiderite and jarosite, $42\text{--}45$ T). Thus, tentative phase identifications needed to be corroborated in spectra taken at more than one temperature. The recoilless fractions also change differently with change in temperature, partly due to differences in the mean particle size and crystallinity.

An apparent increase in the spectral area of arsenopyrite after reactor #4 (Fig. 1), accompanied by a small change in parameters, was attributed to the development of a jarosite, $\text{KFe}_3(\text{OH})_6(\text{SO}_4)_2$. The spectra of reactors #4 and #5 saw an increase in the areas of the higher hydrates of ferrous sulphate, melanterite and rozenite, which subsequently disappeared in reactor #6 in favour of szomolnokite, the concentration of which continued to increase in the leach feed and tails at the expense of pyrite (spectra not shown).

The first trace of magnetically ordered phases in the 5 K spectra appear in the reactor #4 spectrum (Fig. 2a). The line widths of these phases were all very broad making it difficult to distinguish between multiple phases or a range of hyperfine fields due, for example, to differing crystallinity of a single phase. Separation of the product from reactor #6 into leach feed and leach tails revealed that almost all the magnetically ordered material went to the tails as hoped. The leach tails component

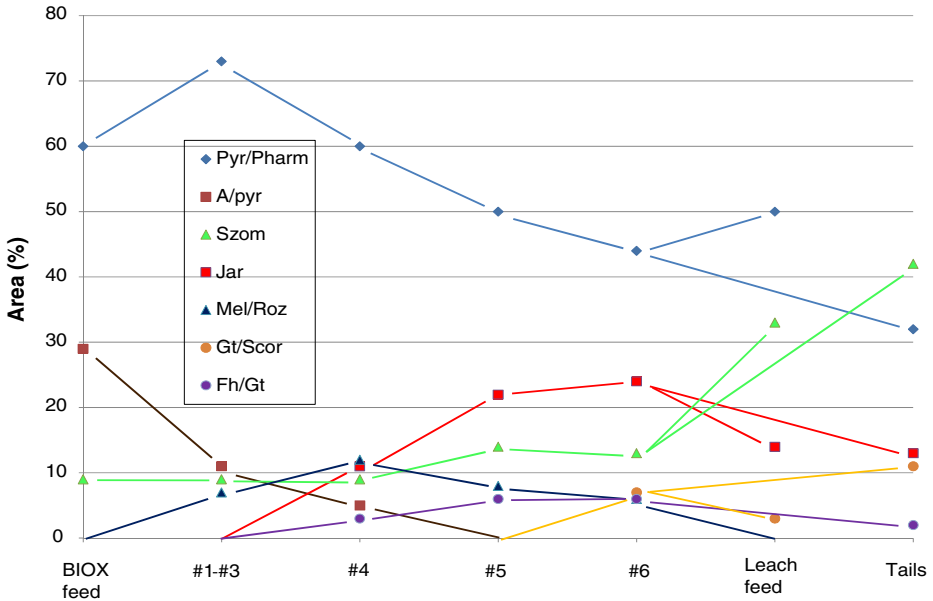


Fig. 3 Phase distribution of iron at different stages through the BIOX plant

also had a very broad and featureless component (Fig. 2b), which could be fitted with a broad Gaussian line and the szomolnokite contribution had become the dominant feature. Comparison of the spectra at 5 K from reactor #6 in zero field and in a field of 9 T is also shown in Fig. 2b and e. The most obvious change is the large increase in the fraction of the spectrum with fields between 44 T and 56 T, all of which was presumably still SPM in the zero field spectrum. The central region is dominated by the remains of the diamagnetic pyrite with a measured hyperfine field of 9.4 T. SEM analysis showed that the original $\sim 10 \mu\text{m}$ particles were reduced to 2–5 μm with large pores, while XRD of the leach feed could not detect any iron species apart from aluminosilicates.

4 Discussion

The changes in the relative proportion of the various iron species is shown in Fig. 3. Points to note are the rapid decrease of the arsenopyrite contribution and the rise and fall of the high hydration ferrous sulphate contribution. It was noticeable that the spectra obtained for the samples extracted from the first three reactors, which are in parallel and nominally identical, showed differences of several percent in the amounts of the two ferrous sulphate subspectra and these values have been averaged. Before the samples were despatched for analyses, they were heated for one hour at 60 °C to prevent further reaction and to keep secret the bacterial composition. However, it was noted that spectra of a second set of samples from the original containers, taken a year later, showed evidence of considerable further reaction.

The only previous Mössbauer investigation of a BIOX system [2] used both ^{197}Au and ^{57}Fe to analyse samples from the Fairview Gold Mine in South Africa. The ^{197}Au spectra showed clearly how the bacterial oxidation released the gold which was chemically bound or occluded in the pyrite lattice. The ^{57}Fe results, which concentrated on the initial and final states of the process, showed almost complete destruction of both the arsenopyrite and the pyrite, with the resulting species being principally jarosite and probably a mixture of poorly crystalline ferric oxyhydroxides. This is a much more complete degradation than what was presently observed, which has presumably resulted in a lower pH and hence the dominant jarosite product. The other distinction is the observation of strong ferrous sulphate contributions, whereas Friedl et al. did not observe any ferrous spectra apart from the pre-existing phyllosilicates.

The fate of the arsenic is not clear. In a previous investigation of gold mine tailings [3], it was found that the arsenic finished as incorporated in ferric compounds, mainly pharmacosiderite and a smaller proportion as scorodite, both magnetically ordered at ≤ 5 K. The related material here is all SPM (Fig. 2b, e) and is a mixture of ferric arsenates and oxyhydroxides. The dominant subspectra in Fig. 2e do not resemble those of goethite or ferrihydrite in a field of 9 T [4].

5 Conclusions

From the present investigation it was shown that the iron products of bio-oxidation of gold ore from Wiluna gold mine were predominantly szomolnokite, mixed ferric oxyhydroxides and smaller amounts of ferric arsenates and a jarosite. The concentrations of higher hydrates of ferrous sulphate were found to reach a peak at reactor #4. There are several ambiguities in the assignments due to the similar parameters of some of the products. It is suggested that a clearer result could be obtained by taking spectra in the region of 20–30 K, which is above the ordering temperature of several of the components, and at 2–3 K for pharmacosiderite.

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