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BACTERIAL LEACHING OF COMPLEX SULPHIDE ORE FROM AKAREM AREA, EGYPT

Bacterial leaching of copper, nickel and cobalt from a complex sulphide ore was studied in shake flask experiments using *Thiobacillus ferrooxidans* at 20 °C. After 20 days of leaching all 90% of Cu, 70% Co and 95% Ni was extracted from the ore. For all sulphide minerals present in the studied ore samples, the data emphasizes that the fastest leaching rates are achieved under oxidizing conditions and low pH (< 2.5) values, where a considerable portion of ferric iron remains in the solution.

INTRODUCTION

Extraction of metals by the application of bioleaching methods holds great promise and will have an important role in the changing scenario of raw material requirements due to low grade disseminated types of mineralization and poor amenability to physical beneficiation. The principle benefits of bioleaching are less labour and energy requirements, lower capital investment and less reduced environment impact (Brierley 1977, Smith, Mishra 1993). Biological leaching of mono- and multiple sulphide ores is an established commercial process (Ahonen, Tuovinen, 1992, 1995; Atkins 1978, Bhatri et al. 1993, Brierley 1978, Bryner et al. 1954). Industrial scale dump and heap-leaching processes are especially suited for low-grade porphyry copper ores, in which primary copper minerals have been altered to secondary sulphide and oxide minerals which are readily amenable to oxidative and non-oxidative acid leaching. Acidophilic *Thiobacilli* play an important role in these processes (Bhatri 1993, Lizama 1988).

The bioleaching of low grade sulphide ore arose from the need to develop economically viable processes in the treatment of low grade ores. Of the total cost of the process where this study represents the results of some fundamental studies on bacterial leaching of complex sulphide as an alternative route of traditional leaching processes.

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MATERIAL AND METHODS

The geologic setting and mineralogy of the deposit have been described by Rasmy (Rasmy 1982). It has been observed that copper nickel sulphide mineralization occurs in association with peridotite, which is considered the principal host rock for the Cu–Ni sulphides which are either disseminated or massive and are generally interstitial to the olivine. Both massive and disseminated sulphides can be distinguished into two phases:

- primary sulphide minerals that include pyrrhotite, pentlandite and chalcopyrite,
- secondary sulphide minerals with pyrite.

Several mixtures of the sulphide ore were tested. Copper was present as chalcopyrite (CuFeS_2) and was associated with pyrrhotite (Fe_{1-x}S) while cobalt was distributed in pentlandite ($(\text{Co}, \text{Ni}, \text{Fe})_9\text{S}_8$) and pyrite (FeS_2). Nickel was present as pentlandite and was associated with pyrrhotite. The pyrite-dominated samples were used in this experimental study. The gangue material was mainly olivine-peridotite. The partial elemental composition of the ore samples is presented in the table.

Table. Elemental analysis of sulphide ore samples (Akarem area)

Sample	Fe, %	S, %	Cu, %	Ni, %	Co, %
A ₁	58.71	36.55	0.16	0.21	0.06
A ₂	60.52	37.03	0.07	0.24	0.03
A ₃	59.56	38.41	0.06	0.1	0.05

The rock material was crushed and sieved into different size fractions (250–90 μm). Samples were dried by placing samples overnight in an oven at 95 °C (14 % moisture content before drying). A dissolution technique was used in preparing powdered samples for analysis by atomic absorption spectroscopy (ASS). This method involves fusion with lithium metaborate (Powell, Somero 1982).

Bacteria and media

Thiobacillus ferrooxidans was obtained from the American Type Culture Collection (ATCC). The media for the growth of the used bacteria were recommended by the ATCC. Medium 64 (*Thiobacillus medium*) for the *Thiobacillus ferrooxidans* is similar to the 9k medium of Silverman and Lundgen (Silverman, Lundgren 1959) and consisted of 0.8 g $(\text{NH}_4)_2\text{SO}_4$, 0.4g KH_2PO_4 , 0.16g $\text{MgSO}_4 \cdot 7 \text{H}_2\text{O}$, 20g $\text{FeSO}_4 \cdot 7 \text{H}_2\text{O}$ and 2ml of 0.5 M H_2SO_4 per liter adjusted to pH 2–8 with 0.5 M H_2SO_4 .

Culture procedures

The growth of *T. ferrooxidans* was carried out in 250 ml Erlenmeyer flasks containing 90 ml of the medium with 10 ml portion of the previous culture, i.e. 10% V/V inoculum without the ore. The flasks were incubated at 20 °C on a rotary shaker at 150 rpm. After 10 days the culture was ready for leaching tests on aliquot preparation.

Leaching experiments

Leaching experiments were carried out in 250 ml Erlenmeyer flasks containing 90 ml of leaching solution and 10g of the ground ore. The flasks were incubated at 20 °C for *T. ferrooxidans*. When the original sulphide from Akarem area was used in leaching experiments, the moisture content had been measured first in order to make 10% ore slurry. pH and redox-potential values of the solutions were measured. Redox potential was measured with Pt electrode using a standard calomel electrode (SCE) as a reference. Dissolved metals were analyzed by atomic absorption spectrometry (AAS).

Sample analyses of leaching solution

During the course of leaching experiments 1 ml sample aliquats of the leaching solution were collected from the supernatant of each flask, the slurry was allowed to settle for 1 h prior to sampling. The samples were diluted to 25 ml with water, filtered and then centrifuged for 10 min at 150 rpm in order to separate the bacterial cells. The clarified solution was then analysed for Cu, Ni and Co.

RESULTS AND DISCUSSION

The results of leaching copper from dry and ground or unprocessed sulphide samples from complex sulphide samples with *Thiobacillus ferrooxidans* are presented in Fig. 1. The copper from the native sulphides was nearly completely leached in 20 days and the copper concentration in the leaching solution was higher than that for dried ground and screened sample. It appears that drying makes a significant fraction of the copper resistant to leaching. Consequently, native samples were used in further leaching experiments. Fig. 1 shows the data when no cells are present in the native sample. It is indicated that more than half of the copper leaching was caused by the action of bacteria. Nickel extraction, as illustrated in Fig. 2, was relatively high (> 90%) at the beginning of the experiments and then decreased during the first 20 days. The maximum rate of nickel extraction at the beginning of the experiment was usually accompanied by a minor increase in cobalt extraction. The decreased rate of nickel extraction may be due to the nickel ions trapping by precipitates (jarosites and ferric hydroxides) formed during the leaching process.

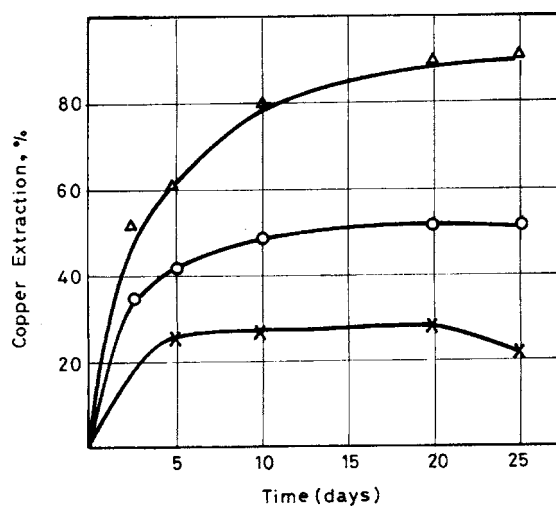


Fig. 1. Shake flask leaching of Cu from Akarem complex sulphide: ○ – *T. ferrooxidans* and dry sample, Δ – *T. ferrooxidans* and native sample, × – native sample

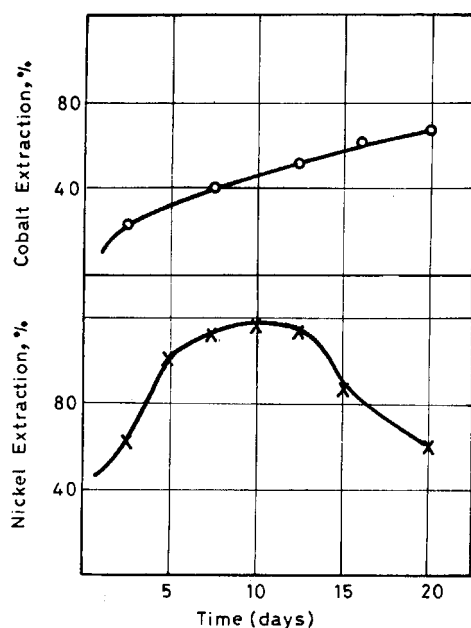


Fig. 2. Shake flask leaching of Ni and Co from Akarem complex sulphide

thermodynamically unstable in oxidative conditions. Pyrite and chalcopyrite have higher electrode potentials and are more recalcitrant than sphalerite, pyrrhotite and pentlandite. Pyrrhotite (the main source of Ni in studied ore) has a low electrode potential and is more dissolved than pyrite as is apparent from the broad pH-redox potential range where nickel dissolution took place.

Effect of pH and redox potential

Figure 3 illustrates general effects of pH and redox potential on the leaching of various metals. The average rates of leaching of cobalt and copper were highest at high redox potential (700 mV) and low pH values (< 2.5) while the leaching of nickel displayed practically no pH or redox potential dependence. The average copper leaching rate increased rapidly at pH < 2.5 and redox potential values 460 mV. The increase in redox potential with time was usually accompanied by an increase in acid consumption and in metal solubilization, while the redox conditions were mainly controlled by bacterial activity and oxygen supply.

The general trends observed here can be due to the electrochemical nature of the sulphide minerals which are

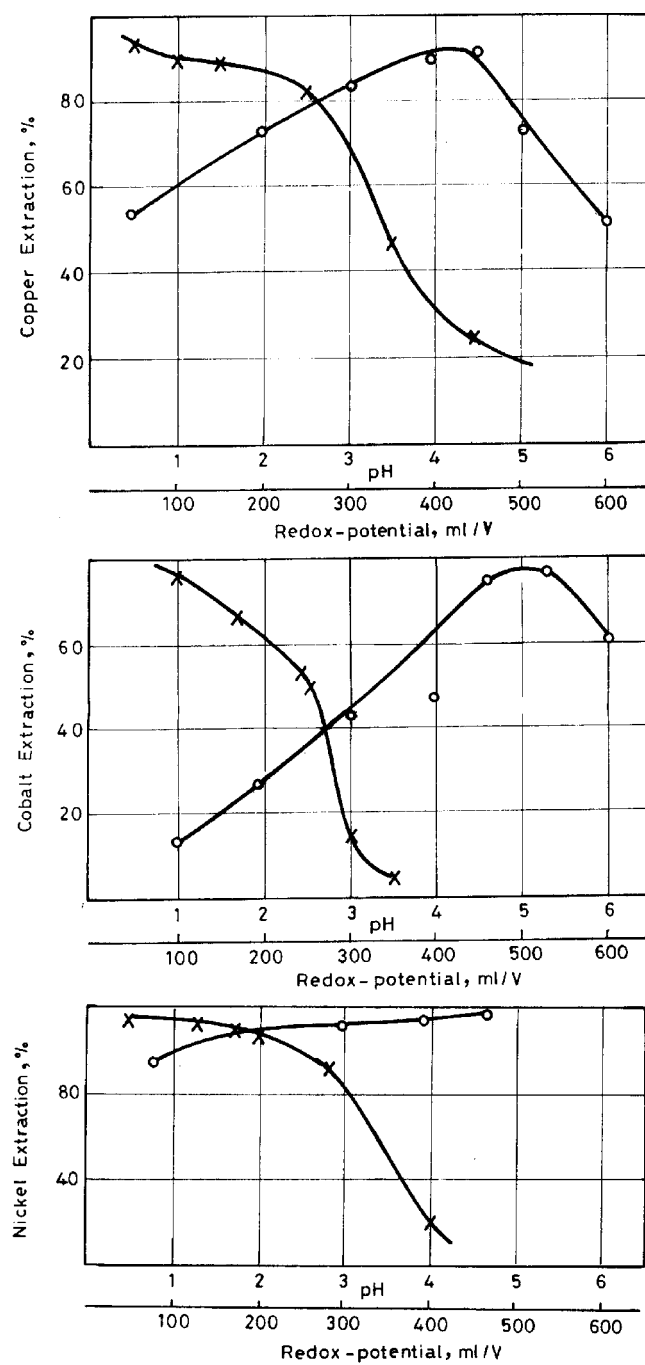


Fig. 3. Extraction of copper, cobalt and nickel as a function of pH and redox potential in flask experiments

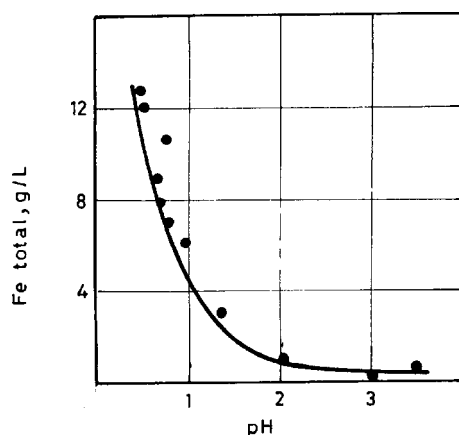


Fig. 4. Relation between total iron concentration and pH

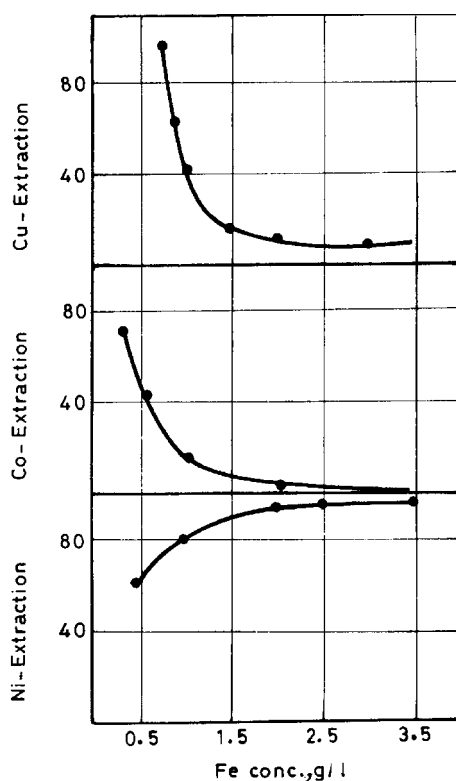


Fig. 5. Relation between metal extraction and concentration of iron

Effect of iron

A significant amount of iron was released from the sulphide minerals during the leaching process where the major part of the dissolved iron was hydrolyzed and precipitated as ferric oxyhydroxide. A compilation of the dissolved iron concentration values as a function of pH in different experiments is presented in Fig. 4.

The solubility of ferric ion precipitates in acid solutions is strongly affected by sulphate which forms stable complexes with soluble ferric ion. The concentration of dissolved ferric ion at $\text{pH} > 2.5$ was negligible, because of precipitation of Fe (III) oxyhydroxide where soluble iron may act as an effective leaching agent whereas iron precipitates may suppress the dissolution processes. It was estimated that in addition to 0.5 mol/l sulphate added for pH adjustment, oxidation of sulfur would produce additional 0.5 mol sulphate/l. Soluble iron precipitates may decrease the dissolution processes. Fig. 5 shows the relationship between the concentration of ferric iron in solution and the extraction of Cu, Co, and Ni. The increased Cu, Co, and Ni extraction when soluble iron was present in the leach solution at low concentration ($< 1.5 \text{ g}\cdot\text{dm}^{-3}$) was observed.

Effect of particle size

The particles' size of the sulphide investigated ranged from 90 to 450 μm . As presented in Fig. 6, the extraction of copper, cobalt and nickel increased with a smaller particle size fraction and at decreasing pH values. This trend is

attributed to the increased solubility of ferric ion and higher redox potential at low pH values which together with the increase of surface area passively affected leaching rates.

Mineralogical examination of the residue

Microscopic examination of the partially leached sulphide ore revealed the common existence of Fe (III) oxide or hydroxide coatings on mineral surfaces. At higher pH values (> 3) the colour of the precipitate was brown, while at experiments conducted at pH value below 2.5 bright yellow precipitates were formed. Covellite was observed to precipitate at high redox potential even if pH of the solution was higher than 2.5 and there was no ferric iron in solution. This indicates that in the presence of ferric iron, the copper sulphide precipitation on the surface of pyrrhotite is a faster process than the oxidation of sulphide.

In complex sulphide ore material galvanic interaction between sulphide minerals may take place. It is indicated from the literature [3] that in chemical controls chalcopyrite was preferentially leached with respect to pyrite when the two minerals were in contact. In bacterial leaching experiments microscopic observations on polished specimens indicated that pyrite was more corroded than chalcopyrite.

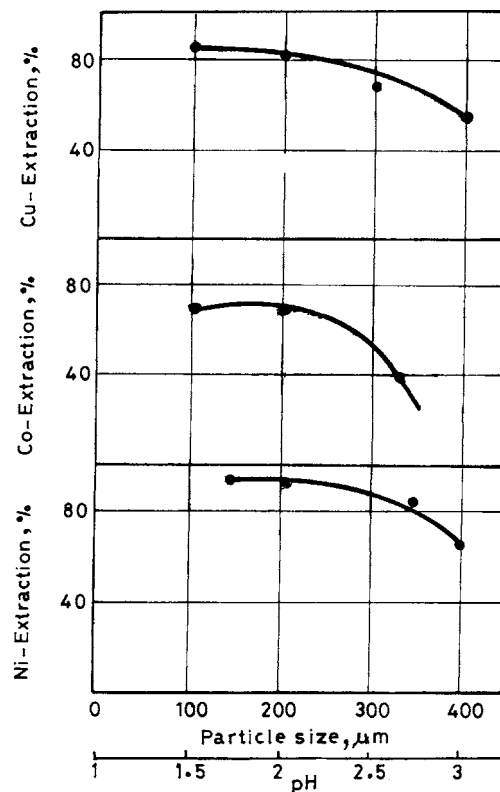


Fig. 6. Extraction of copper, cobalt and nickel as a function of particle size and pH values

CONCLUSIONS

The most significant conclusions that can be drawn from this study are:

- the primary mechanism of bacterial leaching of copper, cobalt, and nickel by *T. ferrooxidans* for the studied Akarem complex sulphide is very likely indirect in which the bacteria catalyze the oxidation of ferrous ions to ferric ions,

- leaching of copper and nickel from native sulphide ores was relatively rapid, with complete leaching occurring only when smaller particle sizes of the native sulphide samples were used,
- leaching of copper and cobalt was found to be most efficient when pH of the solution was adjusted to less than 2.5 and redox potential of about 460 mV,
- the micro-organisms, *T. ferrooxidans*, can adapt to the environment containing pyrrhotite, pentlandite, and pyrite.

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Amer A.M., Ibrahim I.A., ługowanie bakteryjne kompleksowej rudy siarczkowej z rejonu Akarem w Egipcie. *Fizykochemiczne Problemy Mineralurgii*, 31, 43–50 (w jęz. angielskim)

Ługowanie bakteryjne Cu, Ni i Co z rudy siarczkowej przeprowadzono w kolbach laboratoryjnych stosując bakterie *Thiobacillus ferrooxidans* w temperaturze 20 °C. Po 20 dniach wylugowano 90% Cu, 70% Co i 95% Ni. Dla wszystkich siarczków obecnych w rudzie ługowanie zachodziło najszybciej w warunkach utleniających, dla roztworu o pH poniżej 2,5 w którym znaczna część żelaza występuje w postaci jonów w roztworze.