

Bacterial Leaching of Polymetallic Ores from Zlatý Chlum Locality

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Abstract

As for geology, Zlatý Chlum is a highly varied locality with frequent metaquartzite, amphibolite, quartz as well as deposits of sulphide ores. This work deals with the use of *Acidithiobacillus ferrooxidans* to bioleach polymetallic ores (Cu, Al, Zn, and Fe) from this locality. Leaching lasted for 5 weeks in a bioreactor that ensured optimal conditions for bioleaching. The results imply that the experiments were successful, leaching 54% of Fe, 28% of Cu and 47% of Al.

Keywords: bacterial leaching, polymetallic ores, pyrite, chalcopyrite, *Acidithiobacillus ferrooxidans*, bioreactor

Introduction

Description of Zlatý Chlum locality

The processed samples originated from Zlatý Chlum, a hill in the Highlands of Zlaté Hory (Golden Mountains) approximately 2.5 km from the City of Jeseník in the Czech Republic. In terms of geology, it is an ore zone which has been in the centre of miners' interest for centuries. It is made up by a system of quartz lens and veins bound onto varied sequences of rocks, with prevailing mica schist, mica schist paragneiss with inserts of metaquartzite, lime silicate rocks, amphibolites and quartz. Gold occurs predominantly in quartz positions bound onto metaquartzite; it is less scattered in the surrounding rocks made up by granite binary mica schist (garnets as large as 1 cm). It is pure gold, rarely inosculating with tellurides. The content of sulphides (pyrite, pyrrhotite, chalcopyrite) is lower than the content of the dominant rocks. Over 3.5 tons of gold was extracted in Zlatý Chlum. At present, the deposit is not mined due to the low metal content. [1]

Bioleaching

The process of bioleaching may be defined as the dissolution of minerals caused by direct or indirect action of diverse microorganisms. In the course of such processes, the natural flora of microorganisms consists of a mixture of acidophilic autotrophic bacteria. [2] Their role is to produce chemical agents vital for leaching. [3] It is a simple and effective method to recover metals from mineral raw materials, where conventional methods cannot be applied. The fundamental mechanism is the direct or indirect oxidation of sulphide ore. Through oxidation, metal releases into solution, from where it can be recovered using conventional chemical-physical

methods. In this case, we aim to recover metals from sulphide minerals through the activity of bacteria of *Acidithiobacillus* genus, which convert insoluble metal sulphides into soluble sulphates. With regard to the character of the sample, we selected the most suitable species to leach sulphide ores, i.e. *Acidithiobacillus ferrooxidans*. [4,5,6]

Bacteria *Acidithiobacillus*

Acidithiobacillus is considered a biotechnologically and ecologically significant group of bacteria that is the most active in the dissolution of sulphides. It is Gram-negative, acidophilic, rod-like bacteria that thrive in acidic media of a low pH between 1.8 and 2.5. They gain energy from the oxidation of sulphur and reduced sulphur compounds, or via the oxidation of bivalent iron and hydrogen. Considering their metabolic properties, they are suitable to process mineral and electronic waste, and for the desulphurisation of gas and coal. A negative aspect of the metabolic activities of the bacteria is biocorrosion due to the production of sulphuric acid. As for their physiological and morphological characteristics, it shows that *Acidithiobacillus* genus contains at least seven species, e.g. *Acidithiobacillus ferrooxidans*, *Acidithiobacillus ferridurans*, *Acidithiobacillus ferrivorans* and *Acidithiobacillus ferriphilus*, *Acidithiobacillus thiooxidans*, *Acidithiobacillus caldus* and *Acidithiobacillus albertensis*. [7,8]

Acidithiobacillus is a group of microorganisms important for the dissolution of copper, zinc, iron and arsenic from diverse ores, sediments and waste [9]. Their genes determine the transport routes of nutrients, including K, P and Fe, which are vital for the intercellular balance as well as elimination of toxic elements, such as Hg, Pb, As, Cr, Cd and Ag. [10]

Tab. 1. Results of X-ray diffraction
Tab. 1. Wyniki dyfrakcji rentgenowskiej

| Name of mineral | Chemical formula | Content (%) |
|-----------------|---|-------------|
| Quartz | SiO ₂ | 85.38 |
| Sphalerite | ZnS | 0.14 |
| Chlorite | (Mg,Fe) ₆ (Si,Al) ₄ O ₁₀ (OH) ₈ | 1.36 |
| Chalcopyrite | CuFeS ₂ | 2.31 |
| Albite | NaAlSi ₃ O ₈ | 5.94 |
| Orthoclase | KAlSi ₃ O ₈ | 2.30 |
| Pyrite | FeS ₂ | 1.47 |
| Galenite | PbS | 0.73 |

Tab. 2. Leaching of Al
Tab. 2. Ługowanie Al

| Leaching time | Metal concentration (%) | Recovery of metal (%) |
|---------------|-------------------------|-----------------------|
| Input | 2.1301 | |
| 1. week | 1.2059 | 43.39 |
| 2. week | 1.1928 | 44.01 |
| 3. week | 1.1893 | 44.64 |
| 4. week | 1.1406 | 46.46 |
| 5. week | 1.1229 | 47.29 |

Tab. 3. Leaching of Fe
Tab. 3. Ługowanie Fe

| Leaching time | Metal concentration (%) | Recovery of metal (%) |
|---------------|-------------------------|-----------------------|
| Input | 2.51 | |
| 1. week | 2.48 | 1 |
| 2. week | 2.15 | 14.17 |
| 3. week | 1.75 | 30.05 |
| 4. week | 1.44 | 42.27 |
| 5. week | 1.14 | 54.41 |

Tab. 4. Leaching of Cu
Tab. 4. Ługowanie Cu

| Leaching time | Metal concentration (%) | Recovery of metal (%) |
|---------------|-------------------------|-----------------------|
| Input | 2.343 | |
| 1. week | 2.030 | 13.35 |
| 2. week | 1.844 | 21.29 |
| 3. week | 1.801 | 23.10 |
| 4. week | 1.685 | 27.15 |
| 5. week | 1.651 | 28.08 |

Materials and Methods

The samples come from Zlatý Chlum. Subsequently they were processed in the laboratory of the Department of Environmental Engineering at VŠB-TU Ostrava using a vibrating attrition mill. The samples were ground to the grain size fraction -0.063 mm.

The mineralogical composition analysis of the samples was carried out. An X-ray diffraction analysis was done in the laboratories of the Department of Geological Engineering at VŠB-TU Ostrava. The measurements were carried out on a modernized, fully automated diffractometer URD-6 (Rich. Seifert-FPM, SRN). The following phases were identified in the samples in question: quartz, chlorite, chalcopyrite, albite, pyrite. (See Table 1).

Methodology of bacterial leaching

For the bioleaching process, we prepared 9K medium according to Silverman and Lundgren, in which *Acidithiobacillus ferrooxidans* was cultivated.

The leaching process took place in New Brunswick BIO-FLO®&CELLINGEN® 310 (Figure 1). Having sterilized the bioreactor, 500 g of sample from Zlatý Chlum at 100% grain size under 0.063 mm and 10 litres of 9K medium free of FeSO₄ were inserted inside the bioreactor. After one-hour stirring and homogenization of the suspension, a bacterial culture of *Acidithiobacillus ferrooxidans* in the amount of 880 ml was introduced into reactor. A pre-cultivated culture of *Acidithiobacillus ferrooxidans* from the Institute of Microbiology in Brno was applied.

The bioreactor New Brunswick BIOFLO®&CELLINGEN® 310 is a glass vessel of 14 l. To make the bioleaching process most effective and yielding, it is vital to

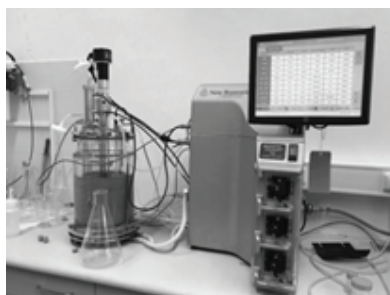


Fig. 1. Bioreactor Bioflo 310

Fig. 1. Bioreaktor Bioflo 310

ensure optimal conditions for the growth of bacteria. The bioreactor Bioflo 310 is able to maintain constant pH of the environment, temperature, degree of aeration, concentration of CO₂ and O₂, and rate of agitation.

Conditions:

- Dissolved O₂: 100/l
- Temperature: 30°C
- pH: 1.8
- Agitation: 150 RPM
- Leaching time: 5 weeks

The samples were leached for 5 weeks. In the course of leaching, samples were drawn after the 1st, 2nd, 3rd, 4th and 5th week. All the samples were washed in 0.1 mol HCl and later in distilled water to stabilize pH. The drawn samples were analysed using a portable spectrometer Dynamic XRF DELTA PROFESSIONAL by BAS Rudice s.r.o. In the course of experiment, the colour of the leached sample changed. At the start, the colour was dark brown and it became lighter during the experiment, which was likely caused by the highly acidic environment.

Results and discussion

The results showed that the application of ATF bacteria disrupted the strong sulphidic bonds and led to the release of metals into the solution. We observed the following metals of interest: Al, Fe, and Cu. We also observed leaching of sphalerite (ZnS), but with regard to its trace concentrations measured by the X-ray spectrometer, we did not determine it further.

Leaching of Al

At the input, aluminium was at 2.13%. In the first week of leaching there was a rapid decrease in Al by 43.39%. In the following weeks, aluminium release continued, but in a less striking speed. From the second to the fifth week, the decrease ranged around 4% (see Table 2). The aluminium recovery after five weeks was 47.29%. It may thus be stated that aluminium may successfully be leached in a bioreactor using the bacterial strain of *Acidithiobacillus ferrooxidans*.

Leaching of Fe

The feed percentage of Fe in the sample was 2.51%. During the first week of bacterial leaching, no leaching bacterial activity was observed. It appears that the bacteria were adapting to the environment and they replicated and grew slowly. As a result, only 1% of Fe passed into the solution

(Table 3). In the second week of bioleaching, there was a prominent increase in Fe release amounting to 14.17%. In the following weeks (third to fifth) the metal recovery grew gradually. In the third week the recovery of Fe was 30.05%, in the fourth it was 42.27% and 54.41% in the fifth.

Leaching of Cu

The input percentage of Cu in the sample was 2.343%. In the first week of leaching in the BioFlo 310, the metal content of Cu decreased to 2.03%, which corresponds to a Cu recovery of 13.35%. In the following weeks, there was a gradual decrease in the sample metal content. After the second week, the solution was enriched by 21.29% of Cu. In the third to fifth weeks, the copper content dropped to 1.651%, which corresponds to the overall copper recovery of 28.08%. (Table 4).

Conclusion

The samples were drawn from the locality Zlatý Chlum, in the Czech Republic. Bacterial leaching was carried out under pilot-plant conditions in a bioreactor New Brunswick BIOFLO® & CELLINGEN® 310 using the bacterial strain of *Acidithiobacillus ferrooxidans*. This strain was selected for its fitness for the sample in question. The drawn samples were ground below 0.063 mm grain size, mixed with Silverman 9K medium and leached with the bacteria in the bioreactor.

The experiment lasted for 5 weeks (35 days) under optimal conditions set for the bioreactor. With regard to the mineralogical composition of the sample, we observed the following metals: Al, Fe, and Cu. The most striking was the course of iron leaching, during which only 1% leached in the first week, followed by a rapid increase to 54% in the weeks after. Copper leaching was gradual and the overall copper recovery was 28%. Aluminium also showed interesting results as it had a recovery of 43% in the first week of leaching, which increased to 47% in the weeks to come. It may thus be stated that bacterial leaching of low-grade ores, as this was the case, has its advantages and may successfully be used as an alternative extraction method, particularly to recover Fe. The disadvantage is the duration of the leaching process.

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Bakteryjne ługowanie rud polimetalicznych z miejscowości Zlatý Chlum

Geologicznie Zlatý Chlum jest bardzo zróżnicowanym złożem z częstymi meta- kwarcytami, amfibolitami, kwarcem oraz polimetalicznymi rudami siarczkowymi. Artykuł dotyczy zastosowania bakterii Acidithiobacillus ferrooxidans do ługowania bakteriynego rud polimetalicznych (Cu, Al, Zn i Fe) z tej miejscowości. Ługowanie trwało 5 tygodni w bioreaktorze, który zapewniał optymalne warunki do bioługowania. Wyniki pokazują, że eksperymenty zakończyły się powodzeniem, uzyskano stopień wyługowania 54% Fe, 28% Cu i 47% Al.

Słowa kluczowe: ługowanie bakteriynne, rudy polimetaliczne, piryt, chalkopiryt, Acidithiobacillus ferrooxidans, bioreaktor