

The application of principal component analysis for bioheapleaching process - Case study: Talvivaara mine



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ABSTRACT

Bioleaching is a complex process which utilizes the earth's natural micro flora for the recovery of insoluble minerals. The process is principally simple although the massive dimensions of the "bioreactor" make the operation and control of heap leaching process demanding.

A multivariate analysis was performed to data collected from Talvivaara Mine's bioleaching heaps. Data were analysed by correlation matrices and principal component analysis. In addition, cross correlation was used to determine a process delay of the bioleaching heaps. Examined process variables were metal contents, pH, temperature and microbial content of the pregnant leaching solution. The most important irrigation variables of the bioleaching process proved to be pH and temperature, together with the Al and Fe concentrations of the irrigation solution. Process delay between irrigation pH and Ni of pregnant leaching solution was found to be 60 days.

Used methodologies provided powerful tools for the investigation of phenomena related to bioheapleaching processes.

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1. Introduction

Bioleaching is a process in which the microbes catalyse the oxidation of sulphide ore, resulting to the dissolution of minerals. This natural process can be utilized for the industrial recovery of minerals from the ores or also the metal containing waste material. Bioleaching can be prepared *in situ*, in heaps or in bioreactors. Bioleaching in reactors is generally more expensive than the other technologies and it is therefore utilized only for the most valuable metals (Acharya, 1990; Dopson and Lindstrom, 1999). The world's largest mine utilizing the bioreactor leaching in Sansu, Ghana produces 1000 t concentrate per day (Mishra et al., 2005). The major benefit of the bioreactors is the improved controllability of process conditions (Dopson and Lindstrom, 1999). *In situ* leaching is based on the explosion of ore to produce breaks into which a solvent can be pumped, followed by collecting of a solution containing metal for further processing. *In situ* leaching is used for the recovery of for example copper and uranium (Aromaa et al., 2013; Mishra et al., 2005). Bioheapleaching is a specific method in which the crushed ore is transferred into the heaps which are then aerated from the bottom and irrigated from the top. It is used for example

in leaching of copper, zinc, uranium and nickel (Acevedo, 2002; Carlsson and Büchel, 2005; Petersen and Dixon, 2007).

The present study has focused on bioheapleaching process at Talvivaara, Finland (Saari and Riekkola-Vanhanen, 2012). Talvivaara mine is the largest bioleaching site in Europe and the only one of its kind in the Northern hemisphere. Talvivaara process has been on function for over seven years during which a vast amount of process data has been collected. In this research the understanding of the bioleaching process and its enhanced control was aimed via the examination of this data. An additional aim was to estimate the response times in the process. These objectives were addressed using a multivariate analysis which allows the simultaneous examination of interactions between leaching process variables and thus enables processing of large amount of data (Pradhan et al., 2010).

The mechanisms of bioleaching are divided to biological, acid and galvanic leaching. Biological leaching is based on a microbial catalysed oxidation of sulphide minerals to metal ions and sulphates. This is commonly an aerobic process in which oxygen acts as a terminal electron acceptor (Eq. (1)).

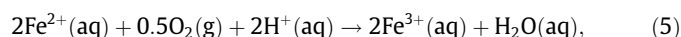
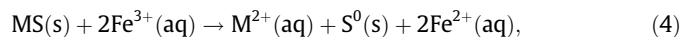
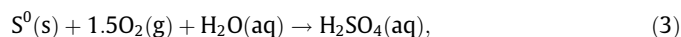
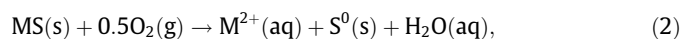


It has been suggested that this process may occur directly, i.e. attached cells would enzymatically oxidize minerals (Eqs. (2) and (3)), or indirectly via oxidation of ferrous iron to ferric iron which

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then reacts with the mineral (Eqs. (4) and (5)). The existence of direct leaching has been under debate and it is also possible that it would actually consist of two indirect leaching reactions (Crundwell, 2003; Sand et al., 2001). Indirect leaching may occur in solution or in exopolysaccharide layer on mineral surface. In addition to iron also elemental sulphur can be oxidized by microbes which promote low pH in the environment and this beneficial for the process (Giaveno et al., 2011; Sand et al., 2001).



Multivariate analysis is used for the examination of interactions between several factors as described for example in Romagnoli and Palazoglu (2006). The data consists of a large amount of observations which are assumed as a random sample of normally distributed results. A proper amount of data points is 200 or more. Multivariate analysis is started with the examination of the observations in order to modify or remove the outliers (the data points that differ significantly from the normal data points) and the lacking data points, and to evaluate linearity. This examination should be prepared via both graphics and the statistical parameters.

In this methodology the outliers are examined based on their origin. The removal of typing errors may be justified, although generally the removal of observation is not advisable. Instead of removal observations may be transformed e.g. logarithmically. The lacking observations can be ignored or they can be filled using interpolation; this only applies to short frequencies and interpolation over long time periods is not advisable (Romagnoli and Palazoglu, 2006).

Multivariate analysis starts with the classification of variables as independent (IV) and dependent variables (DV) (Tabachnick and Fidell, 1989). In this work mainly the factorial analysis and especially principal component analysis (PCA) was used to include the variances of all variables in the investigation (Tabachnick and Fidell, 1989). This method is well suitable for the situations where a large amount of variables needs to be re-grouped to a selected amount of main groups. Therefore, PCA is especially useful for the reduction of variable quantity for the improved understanding of process behaviour.

2. Material and methods

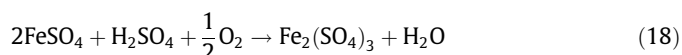
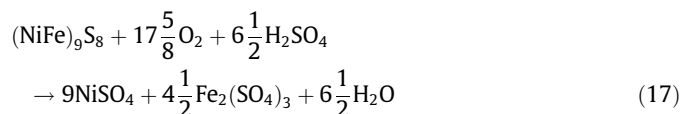
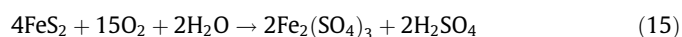
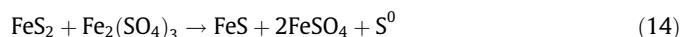
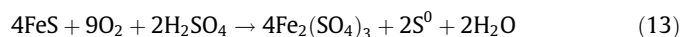
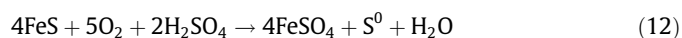
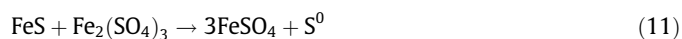
2.1. Description of Talvivaara process

The Talvivaara deposits are located in Eastern Finland, within the Kainuu Schist Belt in ore body of 8000 square kilometres (Saari and Riekkola-Vanhanen, 2012). The average metal content of the ore at a cut-off of 0.07% of nickel is 0.23% Ni, 0.50% Zn, 0.13% Cu, and 0.02% Co. The ore contains also about 0.3% Mg, 10% Fe, 9% sulphur, 8% carbon, and 50% SiO₂. The deposits comprise one of the largest sulphide nickel resources in the world, with 1121 Mt in the measured and indicated resource categories. The major sulphide minerals at Talvivaara are pyrrhotite, pyrite, chalcopyrite, sphalerite and pentlandite.

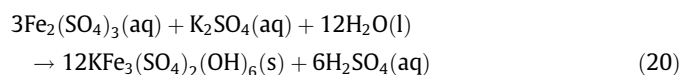
Although Talvivaara sulphide deposits are of relatively low grade, bioheapleaching enables economically profitable nickel extraction from the ore. The production process is described in Fig. 1. Bioleaching initiates with mining of ore from open pit mine. The ore is crushed and transferred to agglomeration. In the agglomeration process the crushed ore is mixed as fine fractions

with pregnant leaching solution (PLS). The agglomerate is then used for building of 350 * 1200 * 8 m sized heaps on a leaching area. Drainage below the heaps is used for the collection of the process solution. The heaps are irrigated continuously from the top with PLS and aerated mechanically from the bottom (aeration tubing installed 0–4 m from the bottom). The primary leaching period takes approximately 11–18 months after which the heap is reclaimed and transferred to a secondary leaching area. Approximately 10% of PLS is pumped to a metal recovery process in which iron, nickel, cobalt, copper and zinc are precipitated. The rinse (raffinate) is used for the irrigation of the secondary heaps. Talvivaara primary leaching area contains of four blocks. The first block was ready during 2008–2009; currently five blocks are already going through the secondary leaching period at secondary leaching area.

The general leaching order of sulphide minerals is as follows: pyrrhotite (FeS), sphalerite ((Zn,Fe)S), galenite (PbS), pentlandite ((NiFe)₉S₈), copper sulphides (Cu₂S, CuS, CuS₂), chalcopyrite (CuFeS₂), pyrite (FeS₂) and arsenopyrite (FeAsS) (Farbiszewska-Kiczma et al., 2004). Although pyrite as such would be leached faster than other minerals, in mixtures it will be the last one to dissolve (Das and Ayyappan, 1999). The main leaching reactions are presented in the Eqs. 11–19).



In addition to the presented reactions also several side reactions take place during the bioleaching process. These include production of iron precipitates (e.g. as hydroxides or jarosites), neutralization reactions due to calcium carbonate and dissolving of aluminium silicates. The production of iron precipitates depends on pH, redox potential and concentration of ferric iron (Bhatti et al., 2010). The accumulation of iron precipitates may slow down the leaching process by preventing the contact between ferric iron and mineral (Ghorbani et al., 2011). Jarosite production reaction is presented in Eq. (20).



Neutralization reactions may reduce the efficiency of leaching via gypsum formation and consumption of sulphuric acid (Eqs. (21) and (22)). Site mineral dissolution also consumes sulphuric acid and the increase of the pH in the heap accelerates the accumulation of jarosite. In high concentrations silicates may also form gels which generally slow down metal leaching.

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