DYNAMICS OF SURFACE WATER POLLUTION CAUSED BY OPEN PIT MINING IN COPPER CONCENTRATE PRODUCTION

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ABSTRACT

The dynamics of surface water pollution around an open pit obtained in the course of pyrite and chalcopyrite mining is studied. The data referring to the water quality in a small river including pH, the river flow rate and the concentrations of Fe^3+, Cu^2+, Mn^2+, SO_4^{2-} and NO_3^- is obtained. The influence of the rainfall and snowfall on the surface water pollution is analysed and discussed. Polynomial models of the river flow rate and water pollutants emission are offered. They can be applied to control the water treatment plant operation.

Keywords: surface water pollution, open pit mining, pyrite and chalcopyrite, pollutants concentration and emission variation.

INTRODUCTION

Acid mine drainage is a huge environmental problem connected with current and abandoned mine operations. It occurs when metal sulfides are exposed to oxygen and water in presence of bacteria. Acid water generation depends also on different factors connected with the materials and landfilling technologies used. It is possible to continue for decades, even centuries [1]. The costs required for mining sites stabilization are of the order of billions of dollars [2].

Chalcopyrite (CuFeS_2) and pyrite (FeS_2) are some of the most common metal sulfides. According to J. Dutrizac and J. Rivadeneira [3, 4] the chalcopyrite ore comprises about 70 % of the copper reserves in the world. It is subjected to pyrometallurgical treatment for copper production after concentration by flotation [5].

The dynamics of the flow rate and the level of water pollution concerning a small river in the region of the open pit mine for pyrite and chalcopyrite are analyzed and discussed in this paper. The study covers five pollutants, namely: Fe^3+, Cu^2+, Mn^2+, SO_4^{2-} and NO_3^-.

EXPERIMENTAL

An open pit mine, whose main output is copper concentrate, was the study site. Tailing heaps were formed in the course of the ore extraction progress. These waste rock materials comprised large amount of minerals of a low content of chalcopyrite and pyrite. They were exposed to climate impact (rainfall and snowfall). An acidic solution containing toxic metal ions in presence of pyrite oxidizing bacteria (most common bacterium is Acidithiobacillus ferrooxidans) was released. As a result, a small river appeared in the region of the open pit mine whose water pH value was lower than 4.0.

Regular sampling and laboratory analysis were carried out for surface water quality monitoring. pH was measured by ASTM E70-07 Standard Test Method of aqueous solutions pH evaluation using a glass electrode. The metal cation concentrations were determined by ISO 11885:2003 Water Quality - Determination of 33 elements by inductively coupled plasma atomic emission spectroscopy using ICP-AES. The sulphate and nitrate anions were determined by Standard Method: 4110 Deter-
RESULTS AND DISCUSSION

The mine drainage acid formation [6 - 8] can be expressed by the following reactions:

\[
\begin{align*}
\text{FeS}_2 + 3.5\text{O}_2 + \text{H}_2\text{O} & \rightarrow \text{Fe}^{2+} + 2\text{SO}_4^{2-} + 2\text{H}^+ \quad (1) \\
4\text{Fe}^{3+} + \text{O}_2 + 4\text{H}^+ & \rightarrow 4\text{Fe}^{3+} + 2\text{H}_2\text{O} \quad (2) \\
4\text{Fe}^{3+} + 12\text{H}_2\text{O} & \rightarrow 4\text{Fe(OH)}_3 \downarrow + 12\text{H}^+ \quad (3) \\
\text{FeS}_2 + 14\text{Fe}^{3+} + 8\text{H}_2\text{O} & \rightarrow 15\text{Fe}^{2+} + 2\text{SO}_4^{2-} + 16\text{H}^+ \quad (4)
\end{align*}
\]

A noticeable decrease of pollutant concentrations in March, April and May (2012 - 2014) is clearly outlined as shown in Figs. 2, 3 and 4.

Fig. 1. Illustrates the mine drainage acid formation in the region of the open pit mine.

Fig. 2. Monthly average pollutant concentrations (mg dm\(^{-3}\)) for 2012.

Fig. 3. Monthly average pollutant concentrations (mg dm\(^{-3}\)) for 2013.
Climate impact

Both rainfall and snowfall vary in years. They influence the process of acid water generation as well as the river flow rate in its own way. The snow melt is a comparatively long process. Depending on the snow quantity this process can cover a couple of months. The rainfall water and a portion of the snow melting water reach the river very quickly. They both can be characterised as surface water, i.e. they do not penetrate deeply into the bulk of the rock material. The latter surface is known to be covered by a passivating film [9 - 14]. That is why the waters in question are comparatively clean. They increase the river flow rate and decrease the water pollutants concentration.

Vice versa, the remaining snow water penetrates into the pyrite and chalcopyrite containing material. It reaches deeper layers under the ground surface. This water remains in the bulk of the rock material for prolonged periods of time and takes part in the processes of pH reduction and pollutants dissolution. It subsequently reaches the river too bringing about water pollutants.

Figs. 5, 6 and 7 illustrate the rainfall and the river flow rate for the years 2012 and 2013.
flow rate variation for the period 2012-2014. It is comparatively high during the spring period because of intensive snow melting. The peaks observed during the other seasons are referred to rainfall events.

The monthly average flow rate of the river F (1 s⁻¹) is approximated by the polynomial equation

\[ F = 197.28 - 329.44 M + 194.06 M^2 - 48.009 M^3 + 5.7939 M^4 - 0.3394 M^5 + 0.0077 M^6 \]

with a coefficient of determination \( R^2 = 0.9486 \). Here \( M \) is the number of the months.

**Emission of water pollutants**

Not only the pollutant concentrations but also the pollutant emissions are very important from a point of view of environmental protection. The pollutant emissions are calculated on the ground of the metal concentrations and river flow rate evaluations. Although the pollutant concentrations are lower during the spring

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Fig. 7. Monthly average rainfall (l m⁻²) and river flow rate (l s⁻¹) in 2014.

Fig. 8. Average monthly emission of pollutants (mg s⁻¹) for 2012.
period, the pollutant emissions are comparatively high because of the higher flow rate of the river. It is noteworthy to mention that pH as a parameter does not change in accord with the pollutant concentrations. The latter decrease even twice during the wet periods, whereas pH varies in a small interval from 3.6 to 4.0.

The monthly pollutant emissions during the period of 2012-2014 are shown in Figs. 8, 9 and 10. A noticeable increase of pollutant emissions in March, April and May is clearly outlined.

The average monthly emissions of water pollutants for the period of 2012 - 2014, shown in the figures above, can be calculated using the polynomial equations listed in Table 1. Here M stays for the number of months, while E denotes the emission of the corresponding water pollutant.
CONCLUSIONS

The emissions of certain water pollutants depend both on the river flow rate and the pollutant concentration. The maximum values of the river flow rate are observed from April to June each year during the period of 2012 - 2014. Eventual rainfall events during the dry periods cause short time demotions of the pollutant concentrations because of pollutants dilution.

Although the concentration of all five pollutants is quite low around April, the emissions are definitely high because of the high flow rate of the river. The latter is a significant factor, because it defines the wastewater residence time in the water treatment plant. This has to be taken into account with regard to its operation.

REFERENCES
