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Long-term environmental impact of tailings deposits

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Abstract

This paper, within the MiMi project, explains the models and the modelling used in the performance assessment (long-term) calculations for the remediation of sulphidic mine tailings. The long-term impact of tailing deposits on the environment is addressed for two types of cover: soil and water covers. Oxygen intrusion is the process that determines the sulphide oxidation and the generation of acid mine drainage containing toxic metals. The primary acidity generated in the tailings from the sulphide oxidation is to a large extent neutralised by the buffering minerals in the deposit. However, when the water leaves the deposit, more acidity is generated due to the oxidation of mainly the ferrous iron (latent acidity). For soil covers, the generated acidity and dissolved metals flow downward with the infiltrating water. However, in a water cover, the reaction products formed may diffuse upwards into the water covering the deposit. Therefore, the acidity is not neutralised in the interior of the deposit. The behaviour of metals/metalloids such as Cu, Pb, Cd and As are also studied. They may be sorbed on the mineral surfaces of the minerals and retained in the deposit for a long time. Some of them may dissolve the more soluble sulphides (e.g., pyrrhotite) and precipitates as secondary sulphides. The data were selected based on experience from primarily Kristineberg (northern Sweden) but also from other sites.

Keywords: Mining waste; Tailings; Pyrite; Long-term; Performance assessment

1. Introduction

This paper, within the MiMi project, explains the models and the modelling used in the performance assessment (long-term) calculations for the remediation of sulphidic mine tailings [1]. MiMi (Mitigation of the environmental Impact from MIning waste) is a multi-disciplinary research programme devoted to development of safe methods for remediation of mining waste and reliable prediction of the long-term function of the disposal sites [2]. The Swedish Foundation for Strategic Environmental Research (Mistra) has funded the MiMi programme for the period 1997–2004. The programme has engaged 35–40 researchers at 7 universities, as well as engineering specialists at consultant companies, the mining companies and the authorities.

This paper describes what happens when oxygen and water intrude into a mine tailings deposit with sulphide-containing minerals. Oxygen reacts with these minerals and generates a stream of acid water that also may contain dissolved heavy metals and other metals. The changes in water composition along the water paths from the infiltration point to a discharge point are studied. Further calculations are made to assess the fate of the water and its dissolved constituents when the water has left the deposit and flows downstream.

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The technique used to model the system is to follow a packet of water in a so-called “stream tube”. This is a fictitious tube that starts at the top of the deposit and continues through the covers and tailings and finally reaches the discharge point. No water flow is allowed through the tube walls. This means that the water volume entering the tube at the inlet leaves the tube at the outlet; but that the stream-tube cross-section may vary in size along the length of the tube. Using this technique, a packet of water can be followed through the system and the chemical reactions in the water and with the minerals can be followed.

The main process that drives the chemical changes in the deposit is the intrusion of oxygen into the tailings, which takes place by molecular diffusion and by advection (dissolved in the infiltrating water). The maximum rate of oxygen intrusion occurs when the chemical reaction rate in the tailings is very fast. Then all the intruding oxygen reacts at once and the oxidation rate is limited by how fast the oxygen can intrude the tailings. However, reaction kinetics may be limiting, especially when there is little resistance to oxygen intrusion. This can occur, e.g., when the sealing layer is damaged or has eroded away. The kinetics of the chemical and biochemical reactions then limits the rate of oxidation of the sulphides.

The oxidation of pyrite, which is the most abundant sulphide mineral in the tailings, produces acidity and releases metals from the sulphides. The acid enables the metals to dissolve and to be carried downstream with the infiltrating rainwater. There are minerals in the tailings that can neutralise the acid produced. In waters that have been neutralised, metals such as copper, zinc and lead that have dissolved into the water when their parent minerals were oxidised can adsorb onto mineral surfaces and they can also re-precipitate as secondary sulphides and not be washed out with the water.

The dissolved iron emanating from the pyrite oxidation is expected to accompany the water and to remain in the effluent that leaves the deposit. This water may be circumneutral because of the earlier mentioned neutralisation processes and it can contain low concentrations of many of the metals of concern. The iron is divalent, Fe(II), and it will be oxidised when it comes into contact with air outside the deposit. This gives rise to the precipitation of iron oxy-hydroxides in the stream and to the production of acidity.

Base case scenarios and data were selected based on experience from primarily Kristineberg (northern Sweden) but also from other sites. Deviations from the Base Case data were used to assess how sensitive to data the results are. Alternative models were used to illustrate the sensitivity to model assumptions.

2. Description of the model

Two methods are proposed to avoid the intrusion of oxygen into the deposit. One is the use of a soil cover consisting of two sub-layers: a protective cover and a sealing layer. In the other alternative, the tailings are covered by water.

2.1. The soil cover

A schematic picture of this deposit is shown in Fig. 1. The section of the deposit with both a protective cover and a sealing layer is addressed. The upper layer (protective cover) physically protects the sealing layer. In the protective cover, some vegetation may be found which may consume some of the intruding oxygen.

The water flow through the deposit is complex. However, for simplicity, it is assumed that the flow is two-dimensional. The cross section of the stream tube varies and depends on the water flux in each location. At any location in the stream-tube, the total flow rate is constant (stream tube definition). In the calculations, a cross-section of 1.0 m^2 is assigned to the stream tube at the top of the deposit.

The stream tube describing this system starts at the surface of the deposit and continues through the protective cover and sealing layer before entering the tailings. In the zone above the water table, the stream-tube is vertical since the water flow is essentially vertical. In the zone below the water table, the stream-tube is inclined due to the horizontal water flow. The protective cover consists of unspecified till and has a thickness of about 1.5 m. The sealing layer is a compacted clayey till with a hydraulic conductivity in the interval of 10^{-9}–10^{-8} m/s with a thickness of about 0.3 m. When compacted, the till has a bulk density of 2250 kg/m^3 and a porosity of 0.18.

2.2. The water cover

The tailings are initially in direct contact with water. With time, sediments may build a layer on top of the tailings. A schematic picture of the system is shown in Fig. 2. Initially, the oxygen intrusion is high because the tailings are in direct contact with oxygen-saturated water. Due to wind and other mixing effects, a flat concentration profile with depth is found. The concentration is equal to the concentration of dissolved oxygen in equilibrium with atmospheric oxygen (about 10 mg/L).