INNOVATIVE METHOD TO DEAL WITH MUNICIPAL WASTE WATER LEADING TO ACID MINE DRAINAGE IN MINING AREAS - CASE STUDIES

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Abstract

In the mines, run off water gets polluted by many reasons. During rainy season the mine water generally mix up with the sulphides, particularly iron sulphides and form a yellowish coloured waste called acid mine drainage (AMD). To deal with AMD is a great challenge as this contaminates the drinking water in different ways and as a result the miners and residents are suffering from different diseases. This AMD further permeates through the ground and pollute the runoff for a long period of time. The permeability of reactive barriers is studied. The toxic levels are tested. Current research in this field includes laboratory batch and column experiments, pilot-scale field tests and full-scale reactive barrier installations. This research has resulted in the development of contaminant removal mechanisms for a variety of inorganics found in groundwater including As, Cd, Cr, Cu, Pb, Zn, Se, phosphate and Acid Mine Drainage (AMD). A brief overview of acid mine drainage, chemistry of it and some innovative methods to mitigate it so that miners and residents won't face difficulties during rainy season due to AMD are recommended.

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Keywords: utilization of water resources, waste water management, acid mine drainage.

Introduction

In surface mining operations, different minerals are overturned. Pyrite is the commonly found minerals in most of mines. When air and water come into contact with pyrite (an iron sulfide), a chemical reaction takes place for which pyrite form sulfuric acid and dissolved iron. This happens when rainwater flows through the site. This acidified water is referred to as acid mine drainage. Iron deposits give acid mine drainage a red or orange color. Water flowing through tailings, particularly through debris from mining operations can cause acid mine drainage very easily. This acidic runoff may also dissolve other heavy metals, viz. copper, lead, or mercury, even sometimes arsenic when come in contact with it. This runoff put huge effects on local streams, waterways, and groundwater and may contaminate drinking water and damage natural habitat. Acidification of streams degrades aquatic ecosystems because most biological life survives within a narrow range, near 7, or neutral. The metals carried in the runoff may also be at toxic levels. Hence highly acidic runoff not only poses a ground waste contamination problem but also a threat to aquatic life. It also poses a great health risk to biosphere. Many diseases occur due to acid mine drainage. Some of the worst problems with acid mine drainage occur in areas where there are abandoned mines whose ownership is a question.

There are various methods for treating and mitigating acid mine drainage, including active and passive procedures. Water treatment plants are the most common example of active procedures. In this

paper, steps are taken to add up alkaline agents to the water to increase the pH levels of this water. Likewise some passive treatments are established which include several natural processes to raise the pH levels and to precipitate the heavy metals out of these water bodies. Passive water treatment improves water quality without much of financial investments as the use of these chemicals are cheaply available in the market. Some passive systems like the use of aerobic wetlands, limestone drainage, or diversion wells have also studied. While these treatments are promising, they have yet to be perfected or widely used.

WHAT IS ACID MINE DRAINAGE?

Acid mine waste pollution is caused by the physical and chemical weathering of a very common mineral. The main culprit seems to be iron pyrite (iron II sulfide) widely known as "fool's gold". The level of acidity and the concentration of heavy metal pollutants in the mine drainage can be directly correlated to the amount of pyrite in the area around the mine. Physical weathering of the pyrite is essential to reduce the grain size of the mineral. The early miners inadvertently accelerated this process by grinding up the ore and dumping the overburden in the mine tailings piles. The next step in this geochemical process is the chemical oxidation of pyrite described in the following reaction:

$$4FeS_{2(s)} + 14O_{2(g)} + 4H_2O_{(l)} \longrightarrow 4Fe^{2+}_{(aq)} + 8SO_4^{2-}_{(aq)} + 8H^+_{(aq)} \quad ....(1)$$
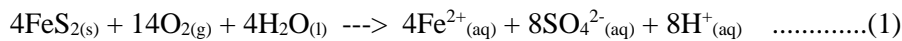
Iron II ions and acidic hydrogen ions are released into the waters that runoff from the mine drainage tunnels or tailings piles. Iron II ions are oxidized to form iron III ions as shown in the following reaction:

$$4Fe^{2+}_{(aq)} + O_{2(g)} + 4H^+_{(aq)} \longrightarrow 4Fe^{3+}_{(aq)} + 2H_2O_{(l)} \quad ....(2)$$
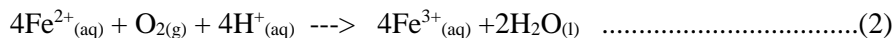
The iron III ions now hydrolyze in water to form iron III hydroxide. This process releases even more hydrogen ions into the aquatic environment and continues to reduce the pH. The iron III hydroxide formed in this reaction is called "yellow boy", a yellowish-orange precipitate that turns the acidic runoff in the streams to an orange or red color and covers the stream bed with a slimy coating. Aquatic life that dwells on the bottom channel of the stream is soon killed off. Eqn. 3 describes this reaction:

$$4Fe^{3+}_{(aq)} + 12 H_2O_{(l)} \longrightarrow 4Fe(OH)_{3(s)} + 12H^+_{(aq)} \quad ....(3)$$
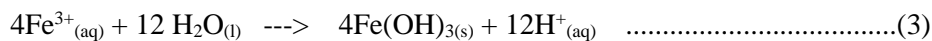
If we were to look at the net effect of Eqns. 1-3, it is find that the pyrite is oxidized releasing acidic hydrogen ions into the water and coating the stream bed with "yellow boy". The sum of Eqns. 1-3 is shown in the following reaction:

$$4FeS_{2(s)} + 15O_{2(g)} + 14H_2O_{(l)} \longrightarrow 4Fe(OH)_{3(s)} + 8SO_4^{2-}_{(aq)} + 16H^+_{(aq)} ....(4)$$
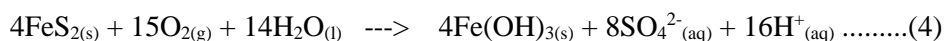
Complex systems in nature such as mine tailings piles and mine draining tunnels cannot be described by just a few equations. Other chemical reactions are occurring as shown in Eqn. 5. In addition, sulfides of copper, zinc, cadmium, lead and arsenic will undergo similar geochemical reactions resulting in the contribution of toxic metal ions into mine waste water. Other factors such as the presence of acidic tolerant bacteria (ex. *Thiobacillus ferroxidans*) can also speed up the process of sulfide oxidation.

$$FeS_{2(aq)} + 14Fe^{2+}_{(aq)} + 8H_2O_{(l)} \longrightarrow 15Fe^{3+}_{(aq)} + 2SO_4^{2-}_{(aq)} + 16H^+_{(aq)} ....(5)$$

Now that we recognize what problems are created by acid mine drainage, we can begin to develop and evaluate possible treatment methods. One such method is an active artificial treatment system. Polluted mine drainage effluent can be diverted to a water treatment plant and treated chemically to neutralize the acid and remove the heavy metal ions. We can also use natural systems that would reverse the process that creates polluted mine drainage. Instead of building costly treatment plants, a simple man-made wetland ecosystem can be constructed at the outlet tunnel of the mine as shown in Fig. 1. Behind the dam, organic matter, bacteria and algae all work together to filter, adsorb, absorb and precipitate out the heavy metal ions and raise pH. This passive system may even concentrate these heavy metals enough so that after a period of time the wetland zone behind the dam may be mined at a profit. The oxidation of sulfide minerals and consequent release of acid in tailings impoundments can last for long. The interaction of the low-pH, metals and sulfate contaminated water with tailings and aquifer minerals initiates a sequence of pH-buffering reactions. This increase in pH is often accompanied by the precipitation of metal-bearing hydroxide and hydroxyl-sulfate minerals that remove dissolved metals from the moving water.
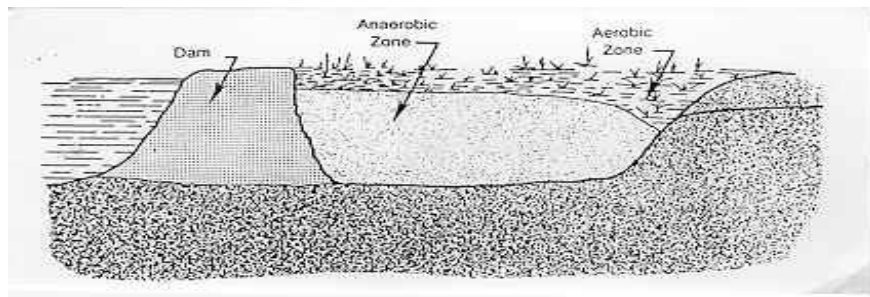

Fig. 1: Diagram of Constructed Wetland Passive Treatment System

METHODS TO DEAL WITH AMD PERMEABLE REACTIVE BARRIERS

Permeable Reactive Barriers (PRBs) are exactly what they sound like: barriers that react with specific chemicals of concern that are placed in the path of groundwater flow allowing the water to flow through easily (Blowes et. al, 2000). It is an *in situ,* passive, reactive barrier for the treatment of inorganic contaminants in groundwater. This method consists of installing an appropriate reactive material into the aquifer, so that contaminated water flows through the reactive zone. The reactive material induces chemical transformations that remove the contaminants or otherwise cause a change that decreases the toxicity of the contaminated water. This research has resulted in the development of contaminant removal mechanisms for a variety of inorganics found in groundwater including As, Cd, Cr, Cu, Pb, Zn, Se, phosphate and Acid Mine Drainage (AMD). Current and past research in this field includes laboratory batch and column experiments, pilot-scale field tests and full-scale reactive barrier installations (Pal and Tandia, 2007).

The barriers are designed to remove contaminants from the groundwater utilizing reaction sequences and mechanisms that result in thermodynamically and/or kinetically stable, solid-phase sinks for the contaminants. A variety of mechanisms including reduction, precipitation and co-precipitation have been exploited to promote formation of solid phase products that are stable in the groundwater environment.

The barrier is generally composed of solid organic matter, like municipal compost, leaf compost, and wood chips/sawdust (Blowes, et. al., 2000). Organic matter encourages the proliferation of sulfate-reducing bacteria that will reduce sulfate to sulfide and will result in the subsequent formation of insoluble metal sulfides. Research has been done to evaluate the efficiency of using PRBs to remove uranium contamination at abandoned mine sites; possible reactive materials are zero-valent iron, bone char phosphate, and amorphous ferric oxy-hyroxide (Naftz, et al., 1999). One important consideration in the design of a PRB to treat AMD is the stability of the metal sulfides. Sulfides have low solubility in anaerobic conditions, if oxidation were to occur metals could be released from their metal sulfide form into the environment (Brooks et al, 1998). PRBs are a relatively new technology and work is continually being done to optimize installations. As it is often helpful to learn from past error a brief discussion of common problems of PRB performance can be evaluated (Mc Rae et al, 1999).
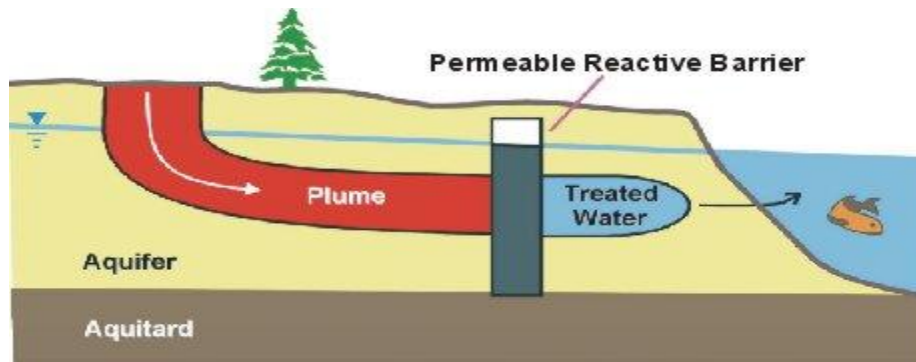
Fig. 2: Permeable reactive barrier

- Although barriers often have very long theoretical treatment lifetimes when only the material and the contaminants of concern are considered, actual lifetimes are considerably shorter due to the presence of other reactive substances in the environment;
- Chemical reactions can be slowed due to depletion of reactive component of the barrier;
- Precipitation of a secondary reactive precipitate can reduce the reactive surface area;
- Physical clogging or preferential path flow.

Permeable Reactive Barrier for Metals and Acid Mine Drainage

Discharge of acidic effluent, often containing high concentrations of toxic trace metals, from mines and mine waste is an intractable, worldwide environmental problem. The oxidation of residual sulfide minerals in mines and mine waste can produce acidic waters containing high concentrations of sulfate, Fe (II) and trace metals. This effluent often enters underlying and adjacent aquifers where buffering by mineral dissolution raises the pH to 4-7. However, on discharge to the surface, the oxidation of Fe (II) to Fe (III) and the precipitation of ferric oxy-hydroxides re-generate acidic conditions (pH < 3), mobilizing toxic trace metals and adversely impacting the surface water ecosystem. Discharge from mines and mine waste can continue for a very long time. Treatment of this effluent is extremely difficult due to the high dissolved

metal concentrations and low pH conditions. A permeable reactive barrier for treatment of As and Ce are shown in Fig. 3.
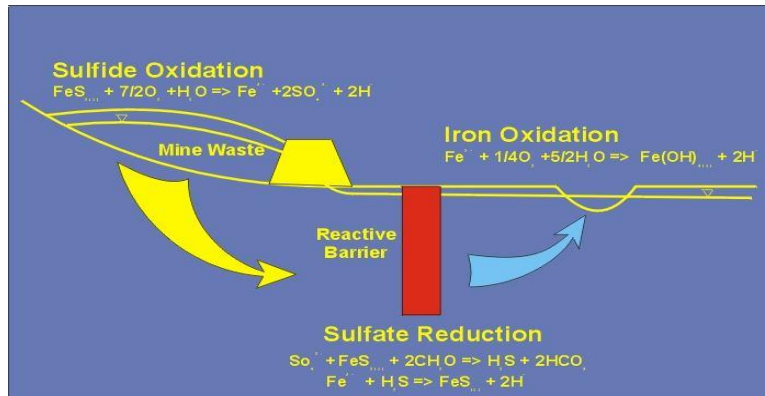

Fig. 3: Permeable Reactive Barrier for Treatment of As and Se

Laboratory Investigations

Arsenic (As) and selenium (Se) are two examples of inorganic contaminants found globally in many aquifers, both occurring naturally in many geologic units and sediments. However, anthropogenic disturbances including agriculture, manufacturing and mining practices and disposal of these associated wastes, contribute to the degeneration of the environment, specifically groundwater resources.

For example, the over-exploitation of groundwater resources found in iron-rich sediments of the surficial aquifers of Eastern India and Bangladesh has led to the contamination of drinking water wells on a catastrophic scale. Approximately 16.7 million people reside in the affected regions and all are at risk of acute As poisoning as these shallow wells represent the only source of drinking water outside the monsoon season. The unforeseen contamination of the many Reservoirs presents different type of environmental pollution by anthropogenic disturbance. Irrigation of high Se soils in this fertile, agricultural valley has led to the release of Se, which is collected in drains terminating at the different Reservoir. The high Se water has resulted in high mortality and deformation rates of waterfowl, which use the reservoir as a sanctuary.

In common pH values of groundwater (pH = 4-8), arsenic exists as As(III) and As(V). The As(V) oxidation state hydrolyzes to form negative oxyanions and As(III) forms a neutral species. Trivalent As is more mobile than As(V) but both are transported in groundwater. The respective Eastern India and Bangladesh drinking water limits are 25 mg/L and 50 mg/L. The most persistent and mobile Se oxidation state is Se(VI) which also hydrolyzes in water to form negative oxyanions. The drinking water limits are set at 10 mg/L and 50 mg/L, respectively (Patel and Pal, 2018).

Both As and Se are toxic and produce numerous, serious acute and chronic health effects, which is reflected by the low regulatory concentrations. This coupled with the possibility of a decrease in the regulatory concentrations; exacerbate the difficulty and cost of effectively treating sites contaminated by As and Se. Permeable reactive barriers offer a unique treatment option for several reasons. These barriers promote in situ geochemical reactions that can lower contaminant concentrations to below regulatory limits and in many cases, below analytical detection. The costs of installation and maintenance are comparatively less

expensive than traditional pump and treat treatment options. Reactive barriers have the potential for the user to, either use the property above the contamination or, "walk away".

Conclusions

Laboratory batch experiments have identified reactive mixtures that successfully remove Se(VI) and both As(III) and As(V) from solution. These optimum reactive mixtures are then used in treatment columns to demonstrate that removal is possible with typical groundwater velocities. Reactive mixtures containing recycled foundry waste, elemental iron and activated alumina capitalize on the unique geochemistry of As and Se for treatment. Surface analytical techniques are then utilized to determine the exact mechanisms of removal. These laboratory investigations indicate that pilot-scale field installations are now possible for the treatment of As and Se.

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