

DESIGN AND IMPLEMENTATION OF A LEACH FIELD TO REMOVE METALS, NITRATE, SELENIUM, AND SULFATE

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Abstract: Soils with good metals attenuation characteristics were evaluated for utilization in a constructed leach field to treat northern Nevada heap leach effluent. Operation of soil test columns showed sufficient attenuation ability for a passive system comprised of caliche and top soils to remove most metals, pH, WAD CN, and arsenic. However, mercury, nitrate, selenium, and sulfate were not attenuated. We investigated the addition of organic carbon amendments to stimulate biological reduction of these constituents within the proposed leach field. Column tests with the organic amendment without any additional non-native microorganisms showed efficient nitrate, selenium, and sulfate reduction as evidenced by effluent water quality. Controls showed minimal removal of these constituents. Based on the data from these column studies, a leach field combining two soil layers and an organic amendment was designed and implemented. Parameters controlling the successful application of this technology at other sites will be discussed.

Additional Key Words: attenuation, microbial treatment, selenium reduction

Introduction

The water quality of effluent from mined materials is often poor. Causes of this poor quality include oxidation of processed ore, overburden material, or waste rock. The oxidized metals and oxyanions produced from these reactions include sulfate, arsenate, selenate, and nitrate. While many constituents of concern, such as metal cations, can be effectively attenuated by passage through soils, these oxyanions in many cases are more poorly removed. Removal of these oxyanions by soil attenuation is for this reason often not considered to be an option for effluent on mine sites. In addition, the depth to groundwater will in many cases limit disposal of effluent bearing these oxyanions in a leach field. Unless groundwater is very deep, groundwater will be affected by infiltration.

Typical treatment options for these oxyanions can include precipitation, coprecipitation, and biological treatments such as sulfate and nitrate reduction, and separation/concentration approaches such as reverse osmosis or ion exchange. These water treatment approaches in many cases have high capital and operating costs. Treated effluent may still require disposal, which in many cases includes infiltration through a leach field or surface discharge.

A method to increase soil attenuation of sulfate and arsenic under a phosphogypsum waste stack was recently developed. This work led to the granting of patents on a process (the Green World Science

process) which adds organic carbon to waste stacks or waste stack-affected zones to prevent groundwater degradation by oxidized constituents (US Patents 5,632,715 and 5,710,361 and others pending). In this paper we extend the application of this process to treat and dispose of waters from a heap leach and an overburden waste rock pile in a soil attenuation field.

To apply this process, we designed a system to receive heap leach effluent in a manner that would be protective of groundwater. This system combined microbiologically performed reduction of sulfate, nitrate, and selenate with soil attenuation in a leach field. The microbial processes transformed these constituents either to gaseous forms (nitrate to nitrogen gas, for instance), into microbial biomass, or created insoluble compounds or forms (sulfate reduction to create sulfide, for instance) that naturally attenuate in soils. This combination of treatment and disposal resulted in a cost effective closure option for a heap leach in Northern Nevada. This approach should prove to be an effective method to treat drainage from heap leach facilities, waste rock dumps, and runoff from surface disturbances.

Design Overview

Soil Attenuation

Attenuation of aqueous constituents during percolation through soils results from their exchange, adsorption on mineral surfaces, precipitation by reaction with soil minerals, or dilution by soil moisture.

The potential for soil attenuation can be tested by percolation of the effluent to be treated through a soil column at a rate similar to percolation rates to be used in the field application. As the water passes through the column, individual constituents are removed at different rates and to different extents depending on effluent and soil pH, soil composition, and many other factors. The heterogeneous nature of soils and the variable constituents of concern make generalization about how soil attenuation will occur for particular constituents nearly useless; however, most soils will remove a similar concentration of cations far more effectively than anions. Consequently, such column tests generally reveal that certain native soils are effective for removing particular cations, less effective

at removing other cations, and nearly ineffective in attenuation of most anions.

Several soils were tested for their soil attenuation properties with effluent from a Northern Nevada heap leach site. Some of the soils tested effectively removed many of the constituents of concern. However, none of the soils tested removed significant quantities of sulfate, nitrate, or selenium (as selenate) after passage of one pore volume of heap leach effluent through the soil column (Table 1). These same results can be seen in time course plots of passage of more than 6 pore volumes through a column containing soil #1 and soil #2 (2 ft. each), with a pore volume exchanged every 14 days (Figures 1).

Table 1. Soil attenuation results.

	Heap Effluent	Soil #1	Soil #2	Soil #3	Soil #4
Parameter					
PH	8.89	7.49	7.67	7.45	7.74
Alkalinity	34.3	38	62.6	61.4	73.3
TDS	2560	1860	2350	5230	2690
Arsenic	0.180	<0.04	<0.04	<0.04	<0.04
Calcium	475	256	350	528	239
Iron	0.099	0.048	0.049	0.063	0.072
Mercury	0.409	0.356	0.084	0.116	0.218
Nitrate-N	103	94.8	96.2	89.2	92.8
Selenium	1.23	0.922	0.988	1.14	1.13
Sulfate	983	769	992	2640	1170

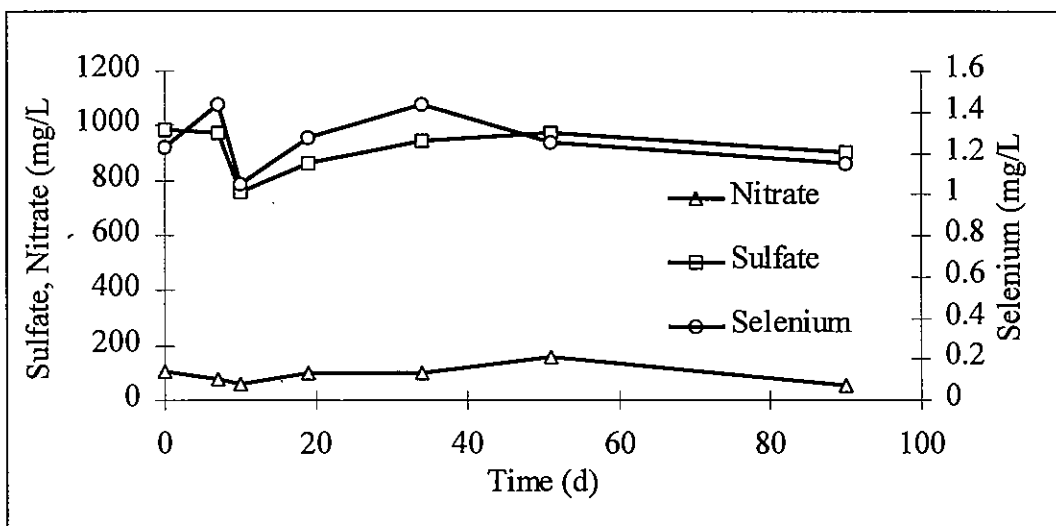


Figure 1. Sulfate, nitrate, and selenium concentrations remain unaffected after passage through 4 feet of soil.

Based on these data, it was recognized that there was limited attenuation capacity in these soils for the oxyanions of concern. However, the soils in the area had reasonable percolation rates, so that a leach field could be operated to receive these residual flows if an alternative method for treatment of sulfate, nitrate, and selenium could be found. Two technologies to remove these constituents were examined for use at this site. These are discussed for comparison with the approach outlined in this paper.

Alternative Technologies

Ion Exchange

Ion exchange was considered to remove these constituents before infiltration. Ion exchange, however, is costly both for capital outlay and operational expenses. Any separation technology produces a brine that requires disposal as well, adding disposal costs to already high operational costs.

Bioreactor

A bioreactor was also considered to treat these constituents. Bioreactors are often constructed with solid waste products such as municipal solid waste, manure, or straw. Though these substrates supply organic carbon to stimulate sulfate, nitrate, and selenium reduction, their operational track record is one of widely variable efficiency depending on temperature and the length of time for which the bioreactor has been operating. Bioreactors can have a limited useful lifetime, and channeling through the substrate as it degrades can reduce the effective hydraulic residence time.

Reduction Field Design Parameters

As an alternative to both of these approaches the Green World Science process was considered. This process utilizes a source of soluble organic carbon, such as sugars and alcohol, as a substrate that is mixed into the effluent to be disposed. This process is designed to perform reductive reactions in natural media, including the mined materials, soil and water affected by effluent from the mined materials, or in constructed reaction zones amenable to performing reductive reactions. The organic carbon is oxidized to carbon dioxide or bicarbonate during the reaction, and aqueous components that can be reduced, such as sulfate, nitrate, or iron, are reduced as a consequence of the organic carbon oxidation. Leach fields constructed to receive mine effluents and to perform these reductive reactions are termed "reduction fields."

Material Selection

To operate optimally, the reduction field needs to be sized to provide sufficient detention time for the microbial reactions to occur. In addition, the field needs to be placed so that oxygen transfer, both in the short and long term, is minimized. The materials used in construction should not release large quantities of constituents as a result of forming reducing conditions. Typical constituents that should be monitored include fluoride, iron, manganese, and silica. In many cases, even if these were to be mobilized in the region where conditions are most reduced, they will precipitate as soon as oxidizing conditions prevail. The permeability of the field needs to be sufficient to infiltrate the effluent, and so that the field is not plugged during the time it is in operation.

Operational Parameters

A water quality goal needs to first be set before planning or constructing a reduction field. If TDS is an issue, and if much of the TDS is contributed by sulfate, the field also needs to be designed to remove bicarbonate. This is because for every mole of sulfate that is reduced two moles of bicarbonate will be formed. Bicarbonate will react with calcium, iron, magnesium, and manganese. In addition, depending on the soil pH, carbon dioxide will off gas, which will also reduce bicarbonate levels. If bicarbonate removal will depend on reaction with divalent cations, such as calcium or iron, sufficient detention time needs to be built into the system for these reactions to occur.

Proper operation of a reduction field requires optimization of the quantity of organic carbon to be added. Factors to be considered in this regard include the water quality goals to be met, the concentration of other oxidized species that might compete for the reducing equivalents generated during organic carbon oxidation, and the physical configuration of the reduction field. In general, the oxidized species that will react in a reduction field are oxygen, nitrate, manganese III and IV, iron III, selenate, arsenate, and sulfate. Determination of an organic carbon dose depends on their concentration during the operation of the reduction field. This concentration includes not only the effluent to be added to the field, but also the forms of these species in the solid phase. The long-term diffusion of oxygen, either from the atmosphere or through plant roots, should also be considered.

A few of the major reactions that will be seen in a reduction field are detailed below (Zehnder and

Stumm, 1988). "CH₂O" refers in a general sense to organic carbon. For instance, glucose will supply 6 "CH₂O."

- (1) $\text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$
- (2) $\text{CH}_2\text{O} + 4/5 \text{NO}_3^- + 4/5 \text{H}^+ \rightarrow \text{CO}_2 + 2/5 \text{N}_2 + 7/5 \text{H}_2\text{O}$
- (3) $2 \text{MnO}_2 + \text{CH}_2\text{O} + 2\text{H}^+ \rightarrow \text{MnCO}_3 + \text{Mn}^{2+} + 2\text{H}_2\text{O}$
- (4) $4 \text{FeOOH} + \text{CH}_2\text{O} + 6\text{H}^+ \rightarrow \text{FeCO}_3 + 3\text{Fe}^{2+} + 6\text{H}_2\text{O}$
- (5) $\text{SO}_4^{2-} + 2 \text{CH}_2\text{O} + \text{H}^+ \rightarrow \text{HS}^- + 2 \text{CO}_2 + \text{H}_2\text{O}$

Using these stoichiometric equations, an organic carbon demand can be calculated. Solid phase amorphous iron oxides, which are generally microbially reducible, can be determined by reaction of the soils with hydroxylamine (Hall and others, 1996). In some cases the native soil will attenuate potential electron acceptors such as iron or sulfate, reducing the effective concentration of these elements that can be reacted in the reduction field. This should be particularly considered in the case of high calcium soils, which receive high sulfate effluents.

In general, complete reduction of sulfate should not be attempted in a reduction field because it is unnecessary. Other problems that may result from excessive sulfate reduction are unreacted sulfide beneath the reduction field, and excess organic carbon leading to metal chelation by unreacted carbon forms such as acetate, and hence the potential for mobilization. Addition of organic carbon sufficient to leave ~100 mg/L sulfate is generally sufficient to completely oxidize the organic carbon and to prevent these problems.

Physical Configuration

The first feature to be examined in considering a site for application of a reduction field to treat residual drainage is the volume of vadose zone. This is determined by the product of the surface area that can be used to infiltrate water and the depth to the closest groundwater beneath that area. Approaches to infiltrate water are considered in detail by Carlson (1999), and will not be detailed here. In general, whatever infiltration system is designed should introduce the least oxygen and should be constructed to be the least sensitive to biological fouling.

In case of shallow groundwater, or to extend operational life of reduction fields, evaporation or

transpiration or a combination of both can be designed into a reduction field. Evaporation will not reduce the carbon demand, but will increase the time between infiltration and potential contact with the groundwater. If rapid contact with groundwater is possible, decreasing the net amount of water that is infiltrated may allow a field to be installed at a location that otherwise might not be feasible. Transpiration of water by plants is another mechanism to reduce the net infiltration of water. If the water quality will allow plant growth in the reduction field, plants have several other benefits in a reduction field. These benefits include deposition of organic carbon through root exudates, decomposition of plant biomass, and maintenance of permeable structures around roots. For some reduction fields, plants could act to provide the long-term carbon source and eliminate the long-term need to add organic carbon. For others, the reduction field could become primarily an evaporation and transpiration field, with the microbial reactions primarily functioning to keep water quality of sufficient quality for plant growth. Selection of plants for inclusion in a reduction field design is a subject too complicated to consider in greater detail in this paper.

Site-Specific Design: Northern Nevada

Native soils that showed some metal-attenuating capacity were selected for pilot-scale testing for use in the reduction field. Two parallel columns, each 4 feet tall and 6 inches in diameter, were used to assess the improvements in water quality in the column effluent as a result of adding organic carbon. The results from the unamended soil column are shown in Figure 1.

The amount of organic carbon to be added to the column was calculated based on the stoichiometry outlined in reactions 1-5. The organic carbon was added along with the heap leach effluent at a rate equivalent to a pore volume exchange every 2 weeks. No additional microorganisms were added to the columns to stimulate microbial activity; it was assumed that the native soil microorganisms would become active as a result of the additional food sources present in the heap effluent that contained organic carbon.

Table 2 compares the effluent water quality from treated and untreated columns after 12 weeks of operation. In four feet of soil with two weeks residence time, drinking water quality effluent was achieved for selenium, nitrate, and sulfate. In the full-scale system, two hundred feet of soil and more than one-year

residence time was available to achieve the final treatment.

Parameter	Heap Effluent	Soil Column (Untreated)	Treated Soil Column
pH	9.10	8.17	7.82
Nitrate	103	49.6	<0.02
Selenium	1.03	1.15	<0.047
Sulfate	983	936	103
Mercury	0.409	<0.0004	<0.0004

Table 2. Nitrate, selenium, and sulfate removal by reduction in a soil column.

Based on these data, a reduction field was constructed to provide an equivalent residence time in the field soils before exiting into a 200-foot thick vadose zone. This vadose zone was expected to provide additional retention time, both to complete any sulfate reduction not accomplished in the field itself, and to provide additional time for compounds to precipitate before contact with groundwater.

Monitoring and Compliance

A down gradient well was chosen to monitor the effectiveness of the treatment in the vadose zone. We decided that bicarbonate would be an effective tracer of the progress of the infiltrated solution. The pH of the solution, as well as the availability of calcium, iron, manganese, and magnesium in the soils and infiltration solution control the concentration of

Figure 2 shows the time course for nitrate, selenium, and sulfate treatment to occur for the column to which organic carbon was added. The order in which these electron acceptors were reduced is the order predicted by the theoretical potential energy yielded by each reaction (Zehnder and Stumm, 1993). This is significant because sulfate has a significantly higher standard for drinking water quality than nitrate and selenium, and treatment can be completed for nitrate and selenium before sulfate removal is complete. In general, sulfate removal will occur after all other constituents that can be removed other than the organic carbon itself.

bicarbonate in natural systems. Thus we would expect that bicarbonate will rise to a concentration reflective of the pH and the solubility products of the carbonate minerals that might form, and remain at that value during operation.

Drinking water quality was the standard with which the down gradient well would be monitored for compliance. It is expected that constituents that are removed by reduction (such as nitrate and selenium) and those removed by sulfidogenesis will not be detected in the monitoring well above drinking water standards. Because the constituents of concern (metals, nitrate, selenium, and sulfate) are the key constituents of concern in this effluent, it is expected that total dissolved solids will only increase by the amount added by bicarbonate.

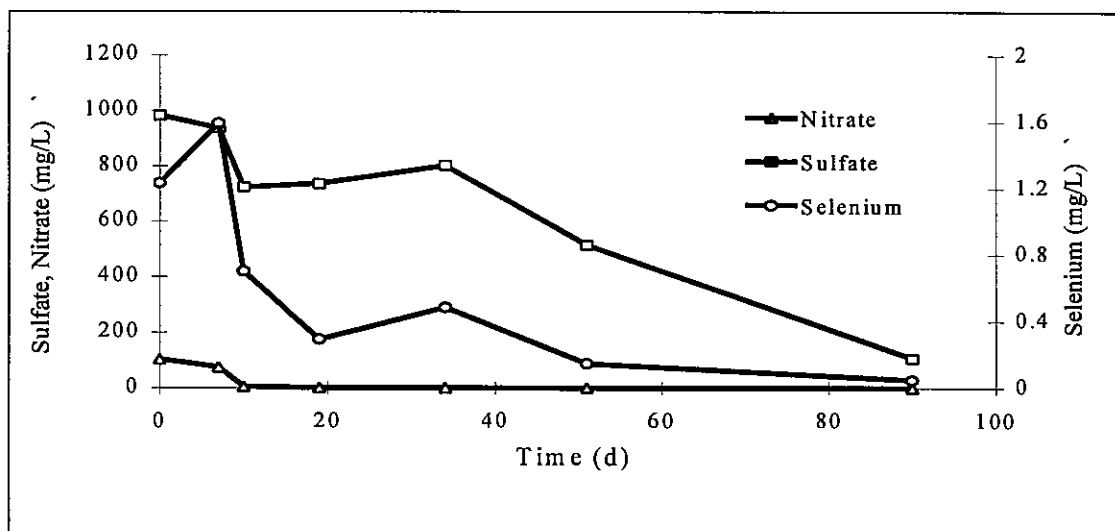


Figure 2. Sulfate, nitrate, and selenium are removed by microorganisms utilizing organic carbon, during passage of effluent through 4 feet of soil.

Conclusions

We have outlined a method to treat mine effluents in an efficient manner. Because this method results in drinking water quality effluents, degradation of groundwater is avoided. Thus infiltration of these solutions can be combined with this treatment as long as sufficient vadose zone is available to supply the necessary time for the biologic reactions to occur.

References

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