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For

TULEYOME

Corona Mine In-Situ Treatment Calibration

Design and Workplan

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BACKGROUND

Team

A contract was awarded to Tuleyome with Burleson Consulting, TKT Consulting, UC Davis and others to implement a project to improve water quality and reduce risks associated with the abandoned Corona and Twin Peaks mercury mines. One goal for the project is to reduce contamination associated with acid mine drainage that discharges from the Boiler House Adit and the Corona Drain Tunnel. The contamination is typical of acid mine drainage, containing high concentrations of iron and aluminum along with other trace metals including nickel. Initially, the team had intended to implement a passive treatment system with infiltration. However, limited space is available and the potential to reduce long-term treatment and sludge handling costs ultimately led the team to consider in-situ treatment.

Project Specifics

The purpose of the water treatment component of the project is to assess the feasibility of an in-situ bioreactor approach. Tracer studies were conducted recently to determine if there was a hydraulic connection between two wells strategically placed as injection points and the water that discharges from the Boiler House Adit and the Corona Drain Tunnel and to determine the residence time. The tracer tests showed that a connection was present and that the residence time may be sufficient to promote biological activity within the underground mine workings, including sulfate-reduction.

Recommendations

The proposed in-situ approach is preferred for several reasons. The acid mine drainage (AMD) at the Corona Mine has high enough metals loading and acidity that it would, at a minimum, require a semi-passive system for long-term ex situ treatment downstream. Treating the water inside the mine could significantly reduce long-term operation and maintenance costs. Sludge handling costs would likely be reduced and could potentially be eliminated. In addition, if the in-situ system is successful at consuming oxygen and slowing the acid generation process, chemical costs will be reduced significantly and the requirement for base addition could be eliminated. If the requirement for base addition is eliminated, power would not be required and the system would only require periodic addition of a carbon source to maintain the biological processes within the mine. Although TKT recommends using alcohol for the carbon source initially, alcohol could be replaced by a less costly waste product for long-term application, which could further reduce operations and maintenance costs. Even if sulfate-reduction is not observed, this test will likely result in a significant reduction in dissolved metals loading from the mine during treatment, assuming the pH can be adjusted appropriately.

Tracer tests showed that the residence time observed at IW-1 was up to 14 days to the drain tunnel and infiltration trench which may be sufficient to promote sulfate reduction, particularly if the treatment area has sufficient surface area for bacterial growth and if flow rates through the injection area are decreased. Based on the tracer test data, TKT recommended proceeding with a short-term (4-month) in-situ demonstration.

A tracer test was also conducted at IW-2. This test showed that IW-2 is also a potential injection point. IW-2 may be used as an injection point in the future, pending the outcome of the proposed treatment using IW-1 as the injection point.

PILOT SYSTEM DESIGN

System Components

The pilot treatment system will include components to add a carbon source and neutralization agent to the mine pool through IW-1. The carbon source will be added as a food and energy source for bacterial growth. The goal is to stimulate the growth of sulfate-reducing bacteria that will reduce sulfate to sulfide resulting in the precipitation of metals as metal-sulfides. Alkalinity will also be generated and oxygen will be consumed. The neutralizing agent will be added to provide a higher pH, conducive to growth of sulfate-reducing bacteria. An inoculum with nitrogen and phosphorous will also be added to ensure that sulfate-reducing bacteria are present and can thrive. Approximately 100-500 gallons per day of spring water will be added to transport the treatment chemicals through the acid generating material to the mine pool. The spring water will be obtained from an on-site spring.

Neutralizing Agent

Sodium hydroxide (NaOH, 25% solution) will be utilized as the neutralizing agent. NaOH was chosen because it can be added continuously with the simple use of a battery powered pump and requires less mixing than solid neutralizing agents such as lime. The NaOH will be transported and stored in 330-gallon totes. The sodium hydroxide will be transferred directly from the totes to the well with the use of a 12V DC peristaltic pump powered by deep cycle batteries. A total of 4 deep cycle batteries will be utilized to power the NaOH pump. Two batteries will be charged and rotated weekly to supply the pump with a continuous source of power for continuous chemical addition.

Continuous addition assumptions:

- Assume average flow rate of 30 gpm = 4,924,800 Liters/month
- Assume an acidity of 287 mg/L NaOH
- Concentration of NaOH = 25%
- Specific gravity of 25% NaOHe = 1.26
- 3.8 Liters per gallon

This dosing rate will require 1,413 kg/NaOH per month

Total volume of NaOH for continuous addition = 698 Gallons/month

at a dose rate of

0.728 mL/L = 2.77 ml/gal

Additional NaOH may be required to obtain a pH that will result in effective metals removal. A pH of 7.5 to 8.5 will likely provide the optimum metals removal in conjunction with sulfate-reduction.

Carbon Source

Ethanol will be utilized as the carbon and energy source to promote growth of sulfate-reducing bacteria to convert sulfate to sulfide for metal sulfide precipitation. Alkalinity generation and consumption of oxygen will also occur as a consequence of biological activity due to the introduction of carbon.

The ethanol will be transported and stored in 330 gallon totes. The ethanol will be pumped to IW-1 in a similar manner to sodium hydroxide delivery.

Continuous addition assumptions:

- Average flow rate of 30 gpm = 43,200 gallons per day
- Divalent metal concentrations of 30 mg/L

The ethanol requirement is approximately 1/3 of that at the Leviathan Mine. The Leviathan Mine Bioreactor was the first field bioreactor to use ethanol as a carbon source. Ethanol requirements are calculated on this dosing rate rather than theoretical chemical equations to provide a more accurate dosing rate under field conditions.

Ethanol dose rate = 0.3 ml/L

1,296,000 gallons = 4,924,800 Liters

1,477 kg/month

Total estimated requirement for continuous addition = 305 Gallons per month

Although it is estimated that 305 gallons per month will be required, initially the dosing rate will be much lower taking care to avoid mobilizing additional iron until the pH is raised and stable.

Inoculum

An inoculum will be prepared by filling 4 five-gallon buckets 1/3 full with aged cow manure. To this, 3 cups of sediment from the Boiler House Infiltration Trench will be added and then the buckets will be filled with water. Approximately 250 ml of distilled ethanol will be divided equally between the buckets. One cup of slurry inoculum from a similar operating sulfate reducing bioreactor at the Nacimiento Mine will also be added to each of the buckets. The buckets will be allowed to stew for a minimum of 4 weeks. The inoculum will be added prior to the startup of chemical addition.

Nutrients

Trace amounts of nitrogen and phosphorus are required for microbial growth. An initial dose of 15 gallons of milk will be added to IW-1 to ensure that micronutrients are present for microbial growth.
The milk will be added with the inoculum. Nitrogen and phosphorous will be added incrementally to IW-1 as commercially available urea and polyammonium phosphate.

Other Nutrients:

- 50:1 carbon to nitrogen ratio is required
- 305 gallons ethanol = 2041 lbs/month

2041/50 = 41 lbs nitrogen required or approximately 132 lbs of urea/month
2041/200 = 10.2 lbs phosphorous or 62.9 lbs of polyammonium phosphate/month

Replacing lost nutrients in drainage waters will be dosed as follows:

Continuous Addition:

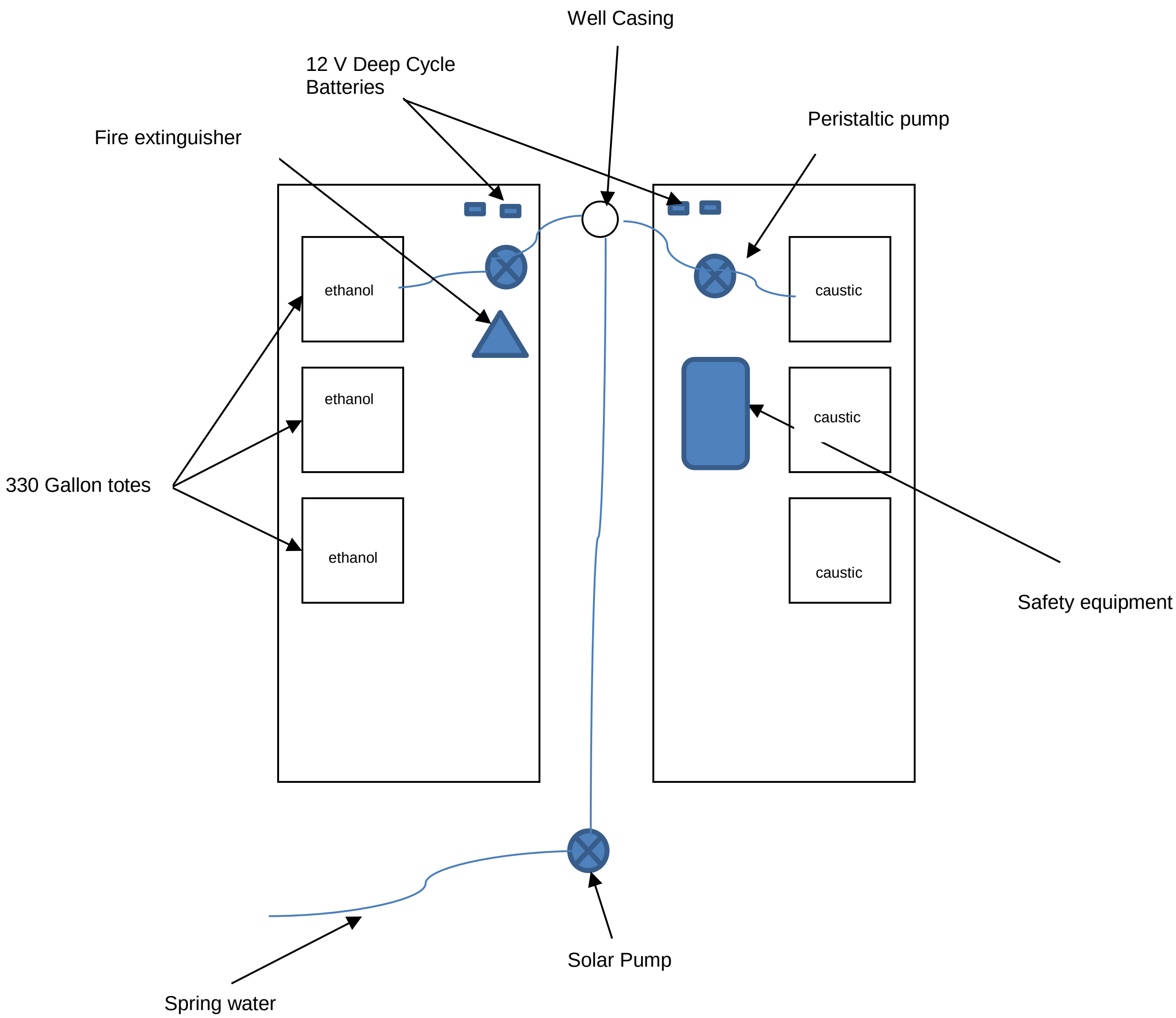
- Urea= approximately 15 lbs will be applied monthly following start-up
- Polyammonium phosphate=approximately 5 lbs will be added monthly following startup

Spring Water

Approximately 100 gallons per day of spring water will be added to the well with a solar pump. A slow continuous addition rate is preferred over batch chasing although flow rates may vary due to site constraints.

Figure 1. Corona Mine EQUIPMENT

In situ Treatment System Diagram



Trailers with Secondary Containment

Two heavy duty utility style trailers with secondary containment will be utilized to house the chemicals. Secondary containment will be utilized to contain any spilled sodium hydroxide or ethanol.

Pump

Sodium hydroxide will be delivered with a Masterflex® L/S® compact, low-flow, variable-speed drive, 12 VDC (or equivalent). Maximum power draw - 3 amps.

The pump should be fitted with L/S 14 pump heads and size 14 Viton and C-Flex tubing to obtain an expected flow rate between 20 and 60 ml/min.

The ethanol will be pumped with the viton tubing and the sodium hydroxide will be pumped with the C-Flex tubing.

Batteries

A total of 8 deep cycle batteries (CR31DC130 MR Crown Marine each with a capacity of 130 Amp-hours or comparable) will be utilized. Two batteries will be utilized to power each pump with a continuous source of power for continuous chemical addition. Batteries will be charged and rotated in weekly.

Holding tanks

Tote style tanks (330 gallons) are recommended for chemical storage. Six tanks of this size will provide capacity for approximately 4 weeks of chemical storage, given the chemical requirements listed above.

Solar water pump

A small solar water pump will be utilized to pump approximately 100 gallons per day of spring water to the well. The pump will be set to deliver water at a low flow rate and provide a continuous flow if possible.

Safety Equipment

Safety equipment will be required for chemical handling. Please refer to the Site Specific Health and Safety Plan.

Assumptions

If sulfate-reduction is established, it can be expected that water quality from the mine will be significantly improved even after the test is completed and chemicals are no longer being added. However, it can be expected that additional carbon will need to be added to the system to maintain a bacterial culture within the mine. TKT envisions supplementing carbon for the long term with a waste product to reduce ongoing costs.

OPERATIONS

Several visits will be required for setup and the initial dosing of milk and inoculum. Following this initial dosing with inoculum, chemical will be metered into IW-1 continuously. This dosing will require periodic visits for minor adjusting and changing chemical transfer totes. The Boiler House adit discharge and Corona Drain Tunnel discharge will be monitored twice prior to starting the test and weekly during the test. The system should be monitored weekly for pH, ORP, DO, temperature and flow rate. Water samples will be taken monthly for metals, alkalinity, ethanol, and sulfate. System monitoring will occur weekly.

STANDARD OPERATING PROCEDURES

The following table lists the project tasks required and frequencies. Additional procedures are provided below.

Table 1. STANDARD OPERATING PROCEDURES			
System Component	Task	Responsible Person	Recommended Frequency
Field Meter	1. Calibrate 2. Monitor pH, conductivity, ORP, DO, temperature and flow rate	Justin	1. Prior to each use 2. Weekly
Pre-treatment monitoring	Field parameter measurements and sampling	Peter Green	Twice prior to implementation of in-situ dosing
Initial Inoculum dose	Add 4 buckets inoculum	Tim	Prior to startup/dosing
Initial slug dosing nutrients	1. Add 15 gallons of milk 2. Add 25 lb bag Urea 3. Add ½ of poly ammonium phosphate	Tim	With inoculum dose
Sodium hydroxide Pump and Ethanol Pump (Continuous dosing)	1. Check/set flow rate using graduated cylinder 2. Inspect tubing 3. Rotate tubing in pump heads	1. Tim 2. Justin 3. Justin	1. Initially 1.5 mL/L (Sodium hydroxide), 0.1 ml/L (ethanol), then according to TKT 2. Each site visit 3. Every 2 weeks
Nutrients continuous dose	1. Add 1/3 bag Urea 2. Add 1/3 remaining polyammonium phosphate	Justin	Monthly following startup
Sodium hydroxide storage	Delivery	Justin	As needed
Ethanol storage	Delivery	Justin	As needed
Monitoring	Measure field parameters and record flow rate	Justin	Weekly
Sampling	Take grab water sample from BH Adit and Corona Drain Tunnel	Peter	Monthly
Battery Charging and change out	Charge and change out	Justin	Weekly
Fire extinguishers	1. Check gauge 2. Have inspected by qualified personnel	Justin	1. Monthly 2. Prior to installation
Eyewash stations	Inspect and check expiration date	Justin	Monthly
General site	1. Inspect for safety hazards or environmental release potentials 2. Inspect ventilation	Justin	Weekly

DATA GENERATION AND ACQUISITION

Sampling Process Design

Field monitoring and sampling will be conducted to support the continued optimization of the project. The overall process of sample acquisition is briefly summarized in the following paragraphs.

Sample Collection and Preparation

Samples will be collected in accordance with Sample Collection Summary. Sampling equipment will be as defined in the governing instructions.

General field parameters will be measured and samples will be collected weekly at the Boiler House Adit, Corona Drain Tunnel, in Kidd Creek above the drain tunnel discharge and in Kidd Creek below the drain tunnel discharge. The field parameters that will be measured are presented in Table 1.

The equipment will be standardized prior to and following each sampling date and when probe is changed, according to manufacturer's specifications. Standardization data will be recorded on forms each time. The probe shall be decontaminated after measurement and before measuring each cell to avoid any cross-contamination. One field duplicate sample and one equipment blank will be taken per sampling episode.

Grab samples will be collected monthly from the Boiler House Adit, Drain Tunnel in Kidd Creek above the drain tunnel discharge and in Kidd Creek below the drain tunnel discharge.

Field parameter measurements will be made in-situ, whenever possible. If an in-situ measurement is not possible, then the measurement will be made after scooping a representative sample from the discharge points using a decontaminated plastic container. Measurements will be recorded in field logbooks. Field meters will be used in accordance with the manufacturer's instructions. At a minimum, meters will be standardized during each sampling event.

Table 2. SAMPLE COLLECTION SUMMARY					
Analyte or Analyte Group	Frequency of Samples or Measurements	Sample Collection or Measurement Method	Sample Container Type/Size	Field Or Laboratory Analysis	Field Preservation
Total Fe, Al, Ni, Cu, Zn, Mn, Cd, Cr	Monthly	Grab, unfiltered	50 ml plastic bottle	Laboratory	Nitric Acid
Dissolved Fe, Al, Ni, Cu, Zn, Mn, Cd, Cr	Monthly	Grab, field filtered	15 ml plastic bottle	Laboratory	After filtering, nitric acid[1]
Sulfate, alkalinity,	Monthly	Grab, unfiltered	100 ml plastic bottle	Laboratory	Iced
Ethanol	Monthly	Grab, unfiltered	100 ml plastic bottle	Laboratory	Iced
pH	Weekly	Field measurement	NA	Field	NA
Temperature	Weekly	Field measurement	NA	Field	NA
Dissolved Oxygen	Weekly	Field measurement	NA	Field	NA
Oxidation Reduction Potential	Weekly	Field measurement	NA	Field	NA
Flow	Every two to three weeks	Field measurement	NA	Field	NA