

Galkeno 900 Sulfate-Reducing Bioreactor Interim Report

2008 Closure Studies

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For ERDC**

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1. PROJECT SUMMARY

A bioreactor has been constructed in the Keno Hill mining district at the Galkeno 900 adit to demonstrate the viability of sulfate reduction technology for the removal of metals, especially zinc and other metals that react with aqueous sulfide. The bioreactor solid phase substrate is coarse rock from a nearby placer mining operation. The organic substrate includes dissolved organic carbon forms, with sugars, alcohols and complex carbohydrates and proteins from milk being used during the growth phase of the bioreactor operation. The purpose of the organic substrate is to support microbial growth until sulfate reduction is the predominant microbial activity in the reactor, and then to support microbial sulfate reduction, which is a microbial reaction that transfers electrons from organic carbon, causing sulfate to be reduced to sulfide. Sulfide reacts with many dissolved metals, forming very insoluble precipitates. The reactor also has the potential for other reactions to occur as a result of alkalinity being formed from the oxidation of organic carbon, and it is common to observe carbonate mineral formation within the reactor. The bioreactor demonstration is being completed under the technical guidance of James Harrington, VP Engineering and Environmental Services with Alexco Resource (US) Corp. Alexco owns six patents and has additional patents allowed and pending for the in-situ use of nutrients in earthen materials. Alexco's technologies and patents provide in-situ encapsulation technologies whereby soluble toxic metals including arsenic, copper, zinc, selenium and uranium, among other heavy metals are geochemically encapsulated by more benign minerals within the groundwater aquifer or within and down-gradient of sources of contamination such as within a pit lake, tailings impoundment, heap leach pad, earth- or rock-filled bioreactor or waste storage area.

Galkeno 900 has water chemistry and flow characteristics that are typical of several other adits in the district. The test is of sufficient scale and will be operated long enough to provide design information that will allow the design of either a large scale bioreactor or an *in situ* reduction field at several other adit drainage locations in the Keno Hill district. The test is operated in a lined bioreactor so that the performance of the technology will be assessed while still in containment, but the results of the tests (reaction rates and stoichiometry) can be extended in the design of either a lined or an unlined system. The operation of the reactor will be continued for at least the next year to demonstrate wintertime operation and compare with summertime operation for metals removal and microbial activity. During the course of the bioreactor demonstration, the conventional lime treatment system is maintained to ensure water licence discharge compliance criteria are met.

Interim results to this point show metals removal close to 88% zinc has been achieved since early May 2009 (5-6 mg/L reduced to 0.5-0.6 mg/L). Other metals have also shown substantial reductions in the same time frame: Antimony ~80% removal (0.0025 mg/L reduced to 0.0005 mg/L), arsenic ~97% reduction (0.068 mg/L reduced to 0.0015 mg/L), cadmium ~60% reduction (0.015 mg/L reduced to 0.005), cobalt ~99% reduction (0.026 mg/L reduced to 0.00015 mg/L), iron ~97% reduction (1.75 mg/L reduced to 0.032 mg/L), manganese ~98% reduction (18 mg/L reduced to 0.25 mg/L), and nickel ~80% reduction (0.2 mg/L reduced to 0.04). While zinc is the primary constituent of concern, the reduction of these other constituents will have beneficial

effects in the reduction of toxicity where elevated metals have a combined toxicity more than any one metal alone.

Conservative elements show less than 10% change during passage through the bioreactor, including calcium, magnesium, silica, sodium and strontium, showing that dilution is not a significant factor causing metal removal in the reactor.

FIGURE 1. GALKENO 900 BIOREACTOR LOCATION



2. BIOREACTOR OPERATIONS

The bioreactor construction occurred in the fall 2008. The following timeline outlines the major events associated with construction and startup:

- July-August 2008: pond construction and lining (see Figures 13 and 14)
- September 2008: pond filling with placement of sand lining layer and placement of rock from placer operation (see Figures 15-17)
- October 2008: pond filling with water began October 4.
- October 2008: 200 lbs sucrose added October 10-11.
- October 2008: 110 gallons methanol and 4 lbs dried milk solids added October 16
- October 2008: covering bioreactor with geotextile and several feet soil cover.
- October 2008-present: occasional “top up” of mine water from Galkeno 900 adit discharge to maintain full conditions in bioreactor in range of 1 m³/day
- January 2009: 110 gallons methanol added January 23
- January 2009: determination of leakage rate from bioreactor: 1.09 m³/day
- February 2009: tank overflow and loss of ~135 m³ water from bioreactor through tank overflow
- May 2009: began adding methanol at a rate of 1 liter per day.

2.1. OPERATIONAL DISCUSSION

The exact volume of the reactor has not yet been determined independently, but the dimensions of the reactor are approximately 100 feet x 90 feet and the depth of the water in the reactor is approximately 10 feet. With an estimated porosity of 0.35, the liquid volume is estimated to be 31,500 ft³, or approximately 235,000 gallons (890 m³).

The volume and residence time of the reactor will be evaluated by injecting a soluble tracer and observing the elution rate and concentration profile. This test is planned for summer 2009.

The slow leakage rate from the reactor requires periodic refilling of the tank located between the adit discharge and the bioreactor. The leakage rate is slow enough to not affect the reactor operation, as it represents approximately 0.8% per week. Ultimately the residence time in the reactor after growth has reached a maximum is designed to be in the range of 1 week.

An upset condition occurred in the bioreactor in February 2009 resulting in the loss of 135 m³ of bioreactor solution. The loss of 135 m³ represented a significant loss of the flowing volume in the reactor, approximately 15% of the total volume. The upset condition was a result of a frozen anti-siphon valve. This upset condition provides valuable information for design of full scale systems in the future. Refilling the reactor with new water appeared to delay onset of sulfate reducing conditions (see discussion of bioreactor performance below).

3. BIOREACTOR PERFORMANCE

The operation of the bioreactor with respect to water chemistry changes is summarized in Table 1 (dissolved parameters), and Appendix 1, which contains all of the field data.

3.1. GENERAL PARAMETERS

The pH of the reactor did not substantially change through the operational period, with the inflow and outflow the reactor in the same range as the pH of the adit drainage. There may be a slight pH increase by passage of adit water through the bioreactor as the carbon source conversion to create alkalinity will have a small pH effect.

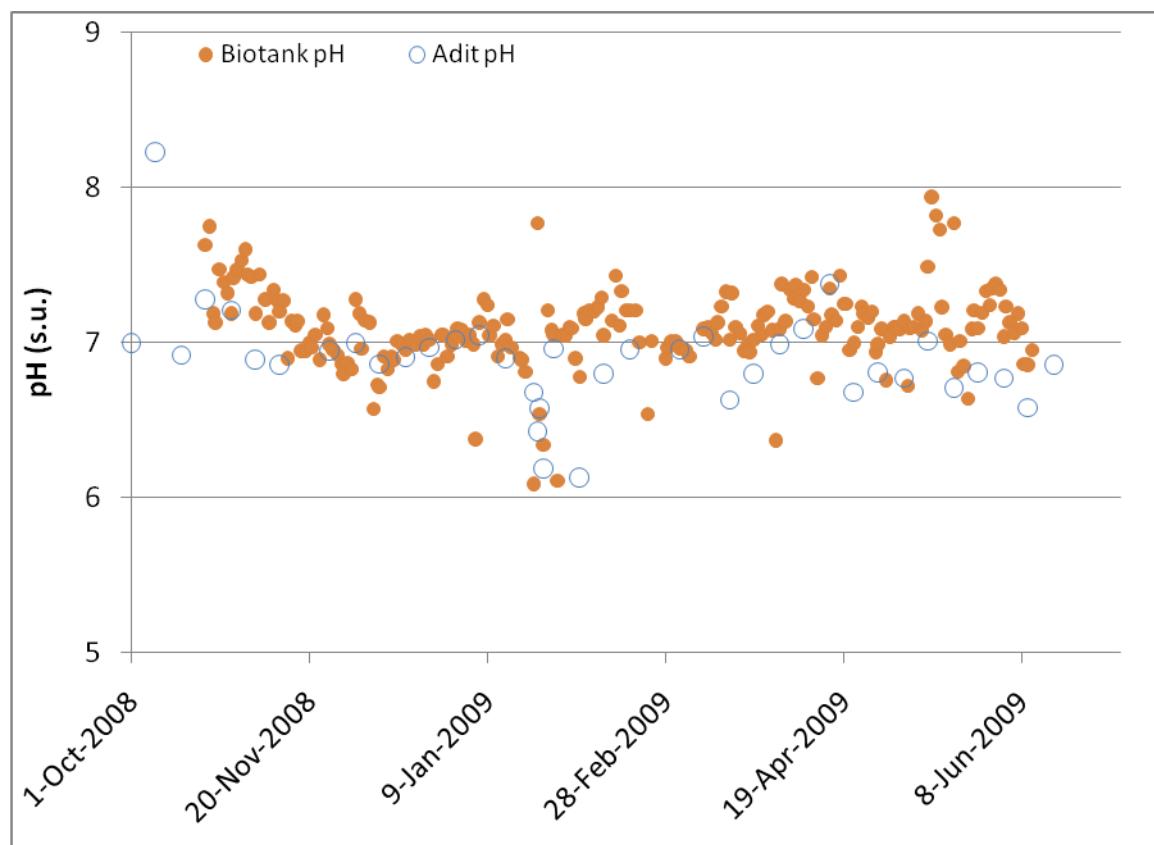


FIGURE 2. COMPARISON OF GALKENO 900 ADIT pH AND BIOREACTOR pH.

Other general parameters that have been tracked at the bioreactor include water temperature and conductivity. The conductivity measurements are not significantly different between the bioreactor and the adit discharge. The water temperature of the adit and the bioreactor shows a substantially different profile, where the bioreactor shows water temperatures to be affected by ambient air temperatures to a greater extent than the adit drainage water temperature. It is important to note that the majority of the growth phase of the bioreactor has been while the water temperature was less than 1°C, a temperature range where psychrophilic (cold-loving) microbes would be expected to be selected.

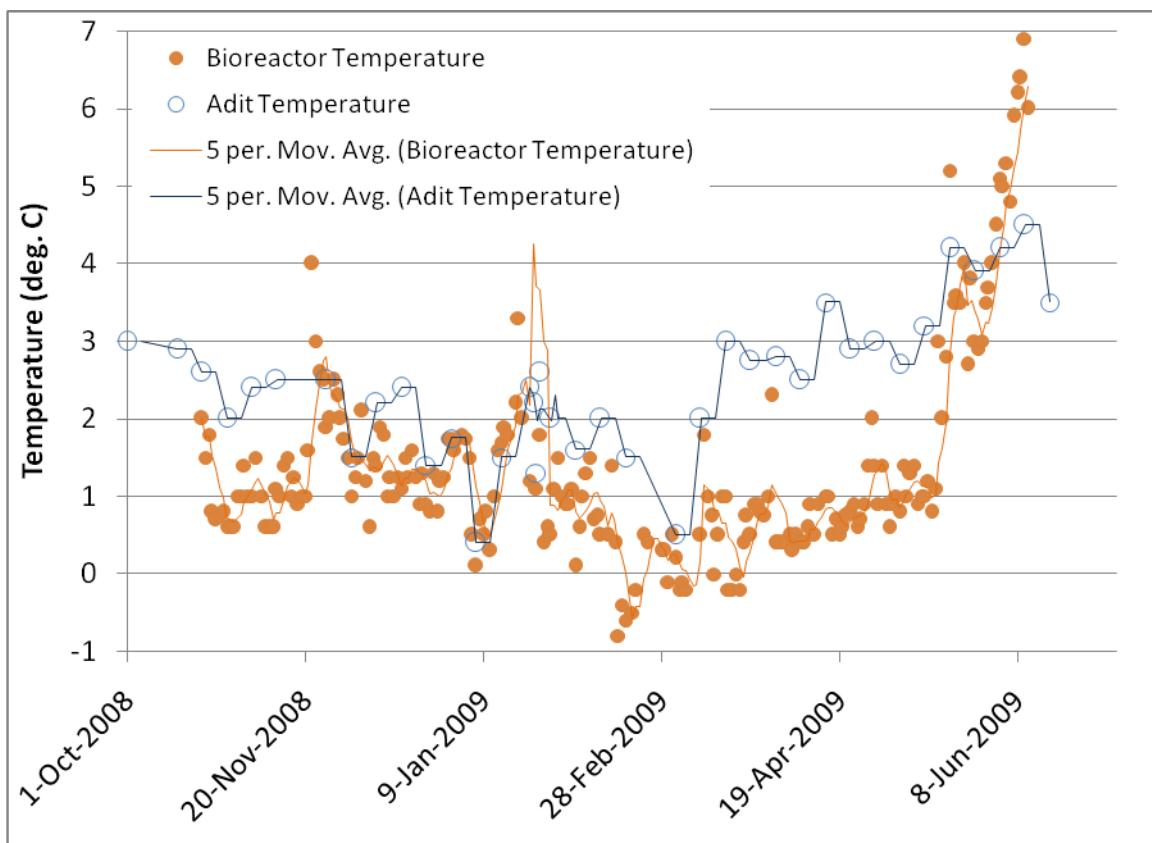


FIGURE 3. COMPARISON OF GALKENO 900 ADIT DISCHARGE WATER TEMPERATURE AND BIOREACTOR WATER TEMPERATURE.

3.2. DISSOLVED METALS

The primary metal being tracked at the Galkeno 900 bioreactor is zinc. However, other metals will contribute to the toxicity of the water, and hence the water chemistry of all dissolved metals have been evaluated. Since suspended solids are very low (due to the settling provided by the existing installed adit plug) the total metals concentrations are the essentially the same as the dissolved metals concentrations. Key metals are discussed below:

3.2.1. Zinc

The concentrations of zinc in the fill water were initially lower than the adit water used to fill the bioreactor. This can be attributed to the dilution of rainwater and snowmelt during construction and initial filling prior to covering the reactor. There may also be a minor component of attenuation of zinc by sorption onto the freshly saturated rock surfaces. However, within a few weeks, and continuing for the first 2 months thereafter, the concentration of zinc in the bioreactor was equivalent to the adit discharge.

Beginning in late January 2009, concentrations of zinc began to fall. This corresponded to development of a biological “organic-sulfide” type odor in the transfer tank. Other metals concentration began to decrease in this same timeframe, perhaps indicative of multiple mechanisms of removal (see Section 4 for further discussion of metals removal mechanisms). By

mid-February, zinc removal was over 60% and this distinctive odor was often noted. The loss of bioreactor water due to icing of the antisiphon valve and the subsequent filling with adit water led to an increase in zinc concentrations for approximately 1 month, until late March. Since that time until early May there was a steady decline of zinc concentrations at a rate of approximately 0.1 mg/L per day. This steady rate is consistent with a direct or indirect biological-growth based mechanism for zinc removal, such as microbial sulfate reduction.

Figures 4 and 5 illustrate the zinc removal using onsite (total metals) and offsite laboratory data (dissolved metals), respectively. There is good agreement with the two data sets. There is also good correspondence between the standpipe sampling location and the transfer tank (Figure 5).

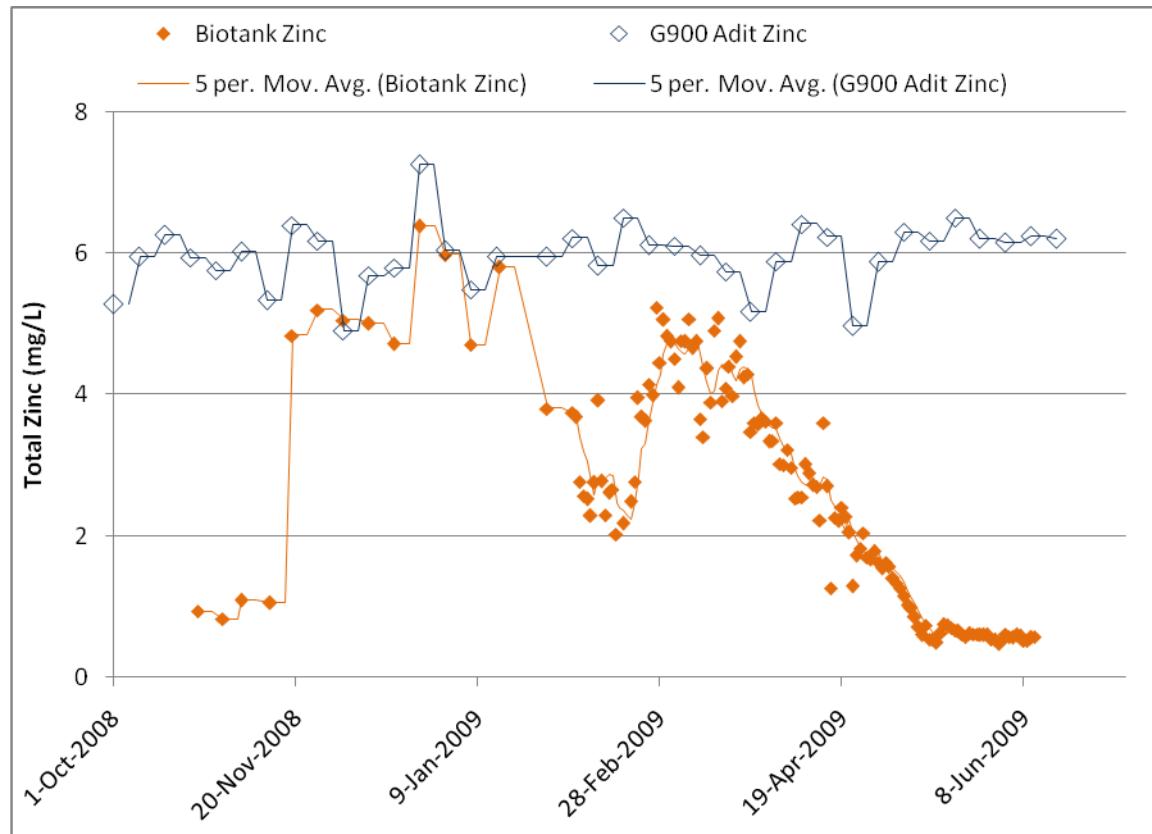


FIGURE 4. ZINC REMOVAL IN THE GALKENO 900 BIOREACTOR USING DAILY SAMPLES FROM ON SITE LAB.

Since early May 2009, the concentrations of zinc have remained constant, ranging from 0.4-0.7 mg/L. The removal of zinc in the bioreactor will be evaluated at different flow rates and as a function of organic substrate loading rates in the next year of operation.

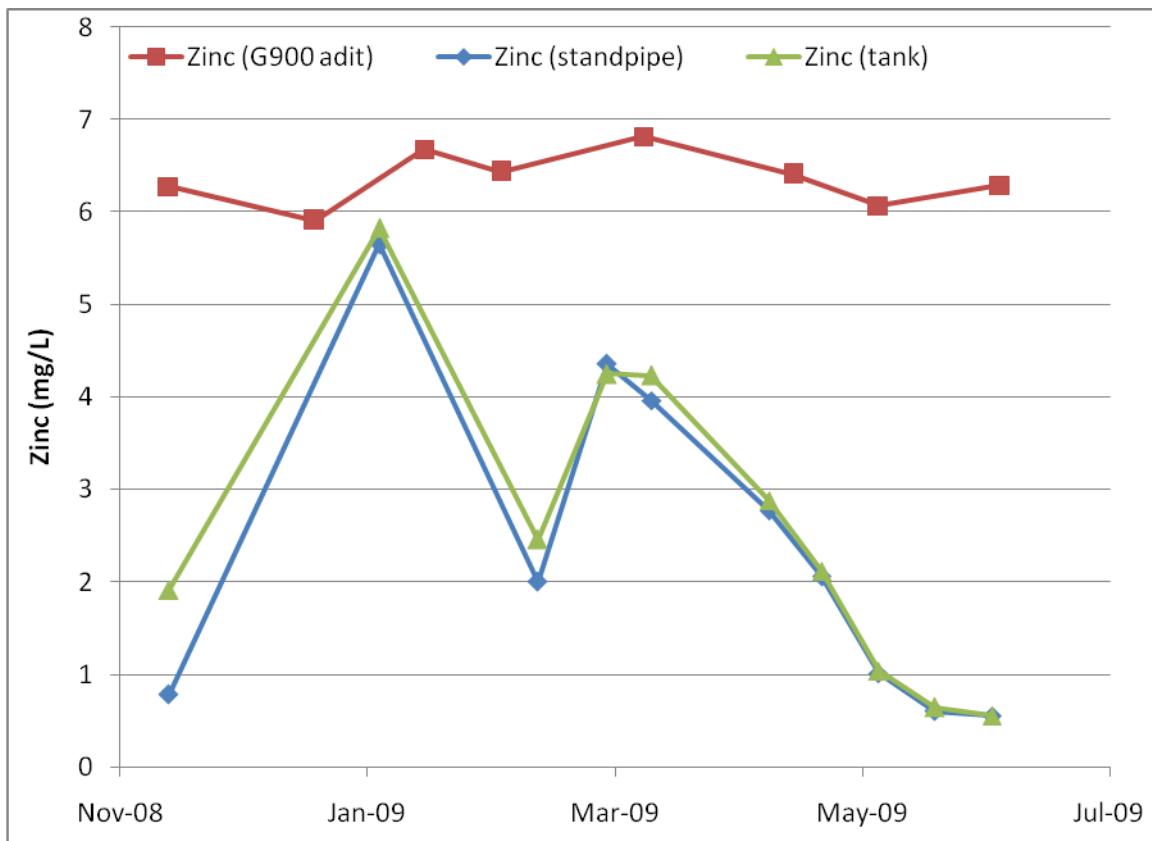


FIGURE 5. DISSOLVED ZINC REMOVAL IN THE GALKENO 900 BIOREACTOR, MONTHLY SAMPLES FROM OFFSITE COMMERCIAL LAB.

3.2.2. Antimony

Antimony concentrations declined approximately 80% during the test (0.0025 mg/L reduced to 0.0005 mg/L average of last 2 months) (Figure 6). Antimony removal in an organic carbon-rich reducing system is typically attributed to an antimony sulfide phase, or by sorption to iron or manganese oxides, carbonates, or sulfides that are stable in reducing conditions.

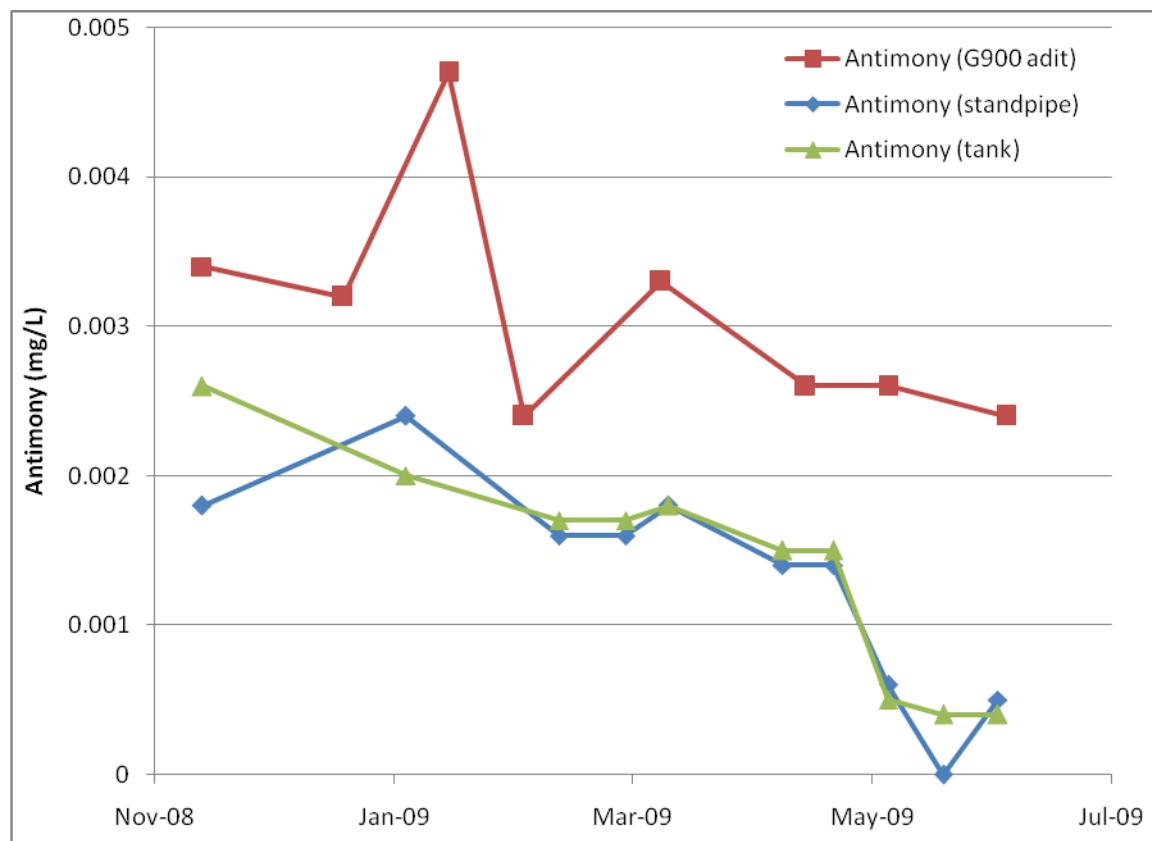


FIGURE 6. ANTIMONY REMOVAL IN THE GALKENO 900 BIOREACTOR, MONTHLY SAMPLES FROM OFFSITE COMMERCIAL LAB.

3.2.3. Arsenic

Arsenic concentrations declined approximately 97% (0.068 mg/L reduced to 0.0015 mg/L average of last 2 months) during passage through the bioreactor (Figure 7). Arsenic removal was substantial from the start, but improved in time, and during the last two months has consistently been between 0.002 and 0.001 mg/L. This graph points to two removal mechanisms, one likely sorptive during initial operational phase, and another precipitation or sorption mechanism that is stronger during the onset of sulfate reducing conditions.

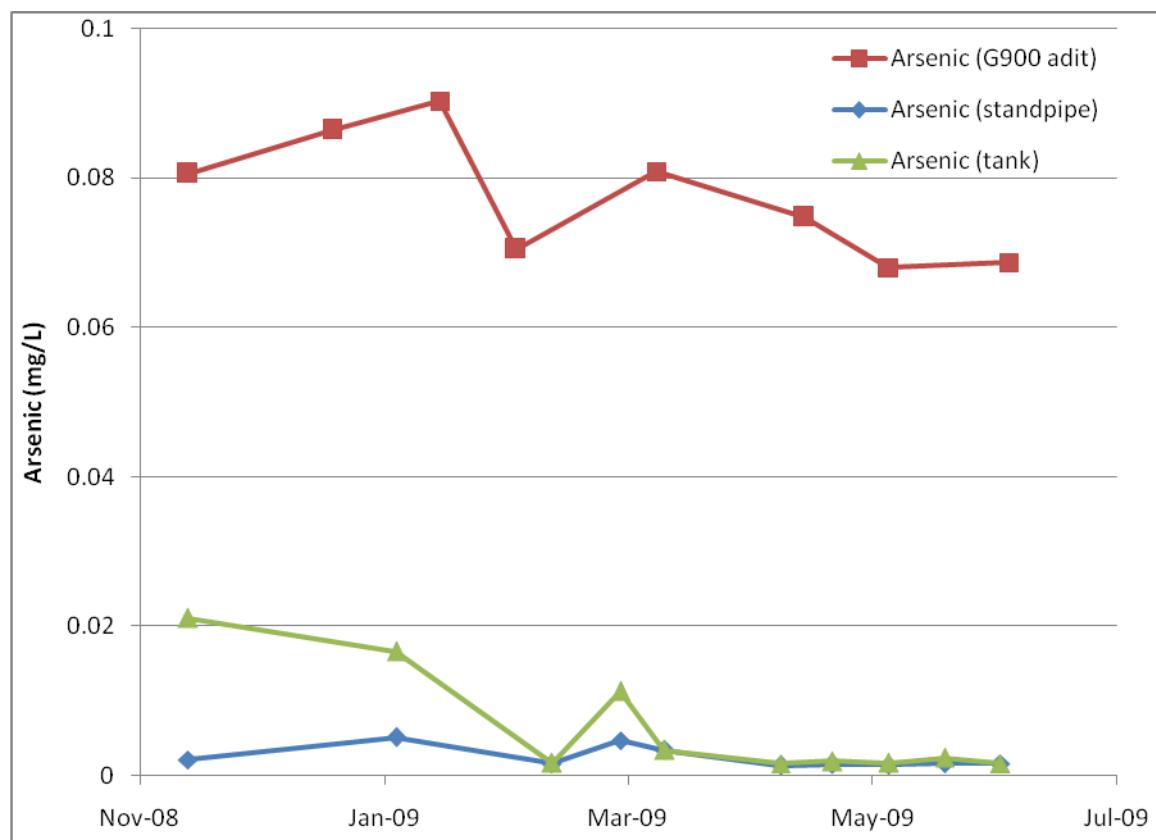


FIGURE 7. ARSENIC REMOVAL IN THE GALKENO 900 BIOREACTOR, MONTHLY SAMPLES FROM OFFSITE COMMERCIAL LAB.

3.2.4. Cadmium

Cadmium concentrations declined approximately 60% (0.0015 mg/L reduced to 0.0005 mg/L average of last 2 months) during passage through the bioreactor (Figure 8). It is important to note that the rock used to construct the bioreactor appears to be a minor source of cadmium, evidenced by slightly higher cadmium concentrations in the bioreactor than the drainage from the Galkeno 900 adit. Thus the last few samples represent over 80% decrease from the baseline concentrations.

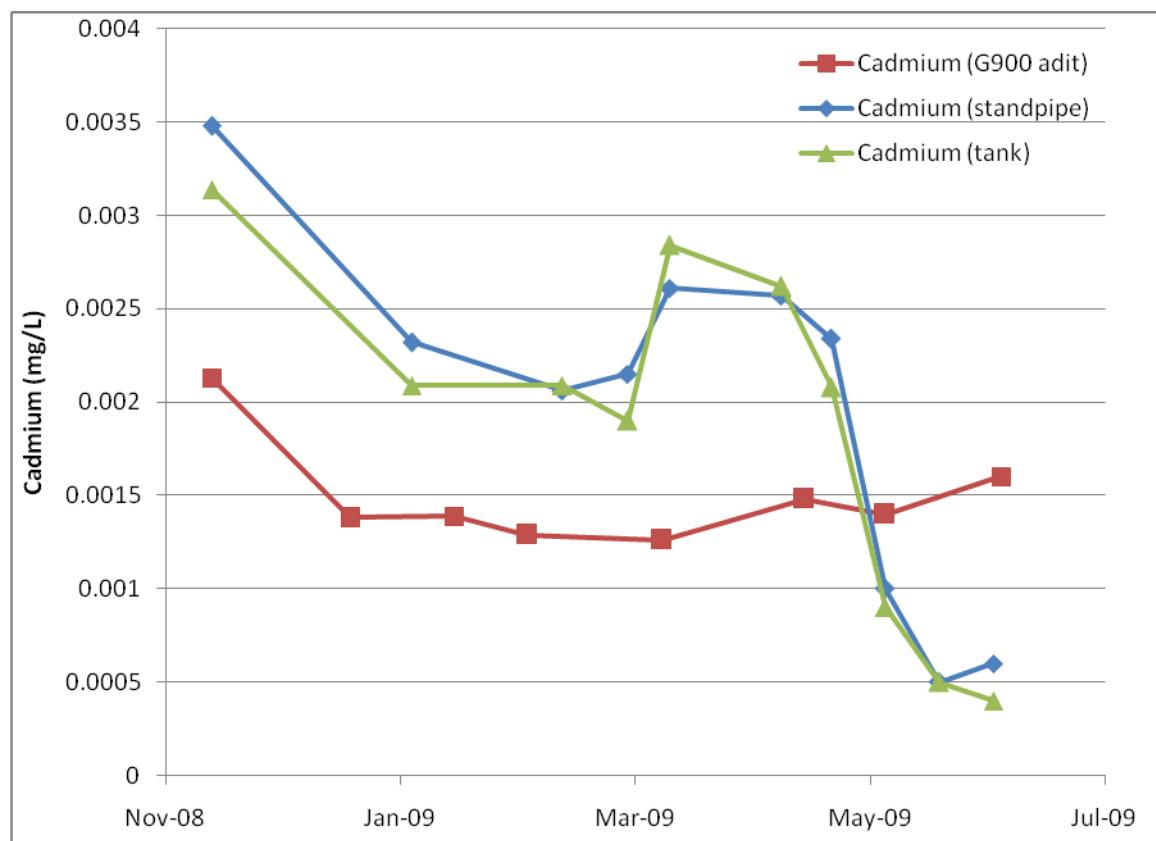


FIGURE 8. CADMIUM REMOVAL IN THE GALKENO 900 BIOREACTOR, MONTHLY SAMPLES FROM OFFSITE COMMERCIAL LAB.

3.2.5. Cobalt

Cobalt concentrations declined approximately 99% (0.026 mg/L reduced to 0.00015 mg/L average of last 2 months) during passage through the bioreactor (Figure 9). Similar to other metals, cobalt removal coincides with formation of biological activity and sulfate reduction.

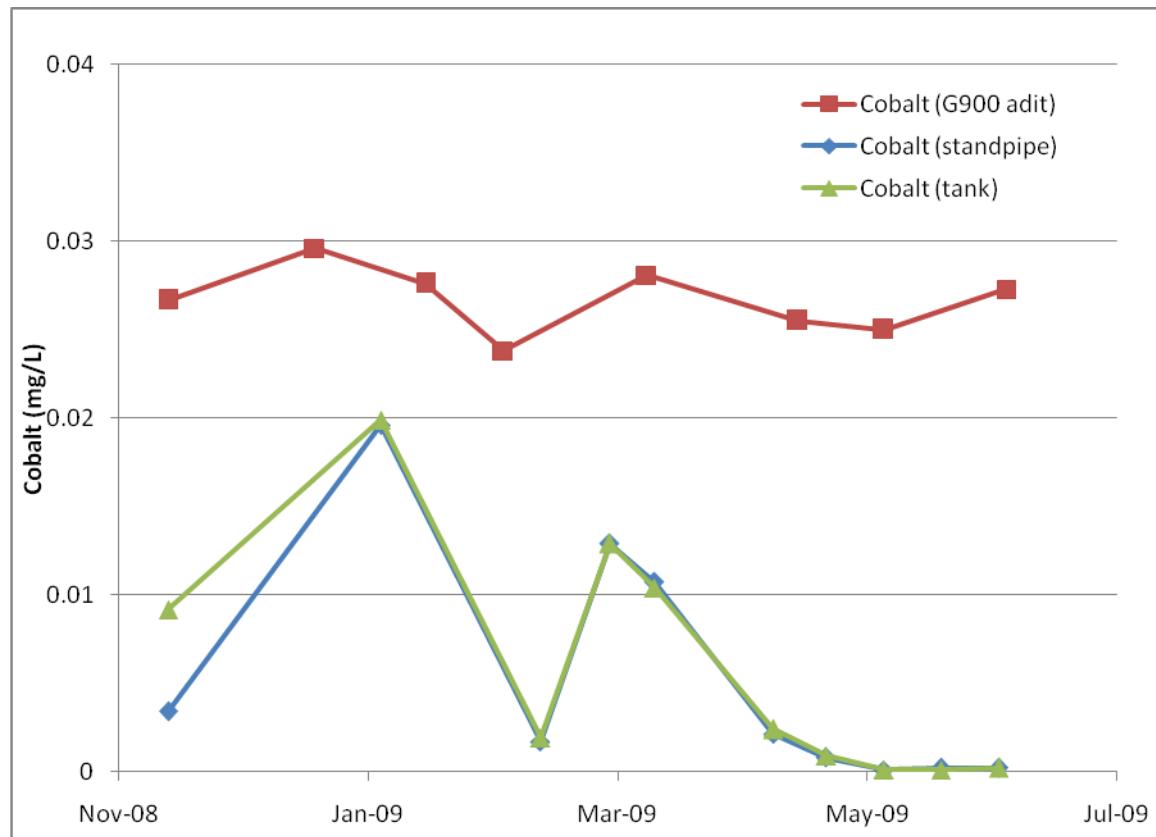


FIGURE 9. COBALT REMOVAL IN THE GALKENO 900 BIOREACTOR, MONTHLY SAMPLES FROM OFFSITE COMMERCIAL LAB.

3.2.6. Iron

Iron concentrations declined approximately 97% reduction (1.75 mg/L reduced to 0.032 mg/L average of last 2 months) during passage through the bioreactor (Figure 10). Similar to arsenic, iron appears to be removed by two mechanisms, one operational immediately in the bioreactor, which implies sorption on the substrate rock or precipitation as an oxide. During the formation of stronger reducing conditions in the last two months, iron removal has continued, but more to a greater extent than in the initial phases of operation.

Iron removal in the bioreactor has important effects for other metals. Iron oxides have good sorption capacity for trace metals. Iron sulfides in their initial amorphous precipitate form (operationally called “acid volatile sulfides” or AVS) provide a sink for sulfide that is a source for preferential reaction with other metals that form more insoluble sulfides than AVS. As such, it provides an important insurance phase during operation of the bioreactor, that if the bioreactor runs out of organic carbon due to imperfect supply, the AVS pool provides continued metals removal capacity, and helps maintain reducing conditions within the bioreactor. The iron in the bioreactor will be the subject of additional study after the test bioreactor is complete.

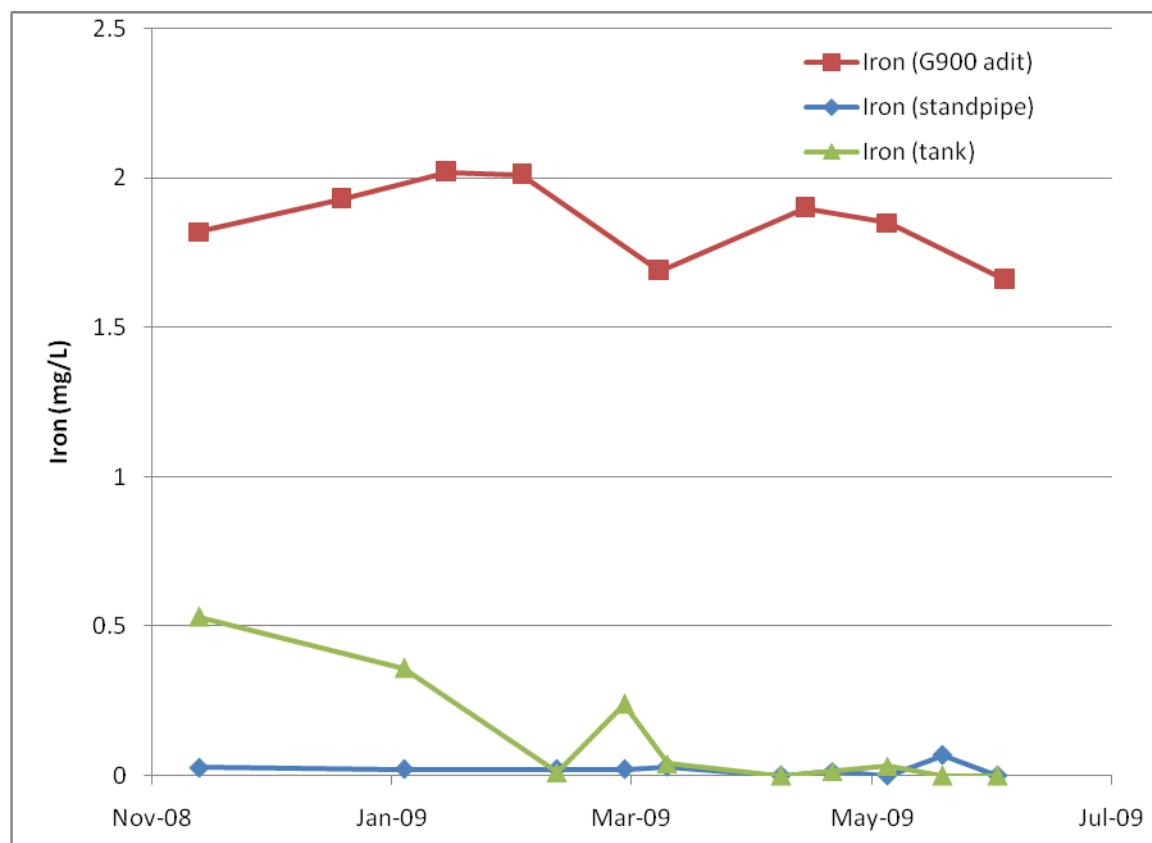


FIGURE 10. IRON REMOVAL IN THE GALKENO 900 BIOREACTOR, MONTHLY SAMPLES FROM OFFSITE COMMERCIAL LAB.

3.2.7. Manganese

Manganese concentrations declined approximately 98% reduction (18 mg/L reduced to 0.25 mg/L average of last 2 months) during passage through the bioreactor (Figure 11). Interestingly, manganese removal appears to coincide with the formation of biological activity, including sulfate reduction. It is often thought that manganese will be soluble in reducing conditions, such as are being generated in the bioreactor, because manganese sulfides do not rapidly form. As a consequence, manganese sinks in the bioreactor are considered to be more likely carbonates than oxides. The fact that the March data point was the same for the adit discharge and the two bioreactor locations, when the bioreactor was at its most oxidized form due to the siphoning of some of the reactor out and refilling with adit water, indicates that it is not an oxide form that is removing the manganese, but that some secondary effect of sulfate reduction, perhaps formation of bicarbonate, is responsible for the enhanced removal of manganese under reducing conditions.

Similar to iron, manganese removal in the bioreactor has important effects for other metals. Manganese carbonates and oxides have good sorption capacity for trace metals. These manganese minerals will sorb trace metals such as zinc without releasing them if the pH becomes mildly acidic, making them a more permanent sink than even iron forms. Manganese precipitates may play a significant role in the removal of metals in the bioreactor. This will be studied further after the reactor operations are complete.

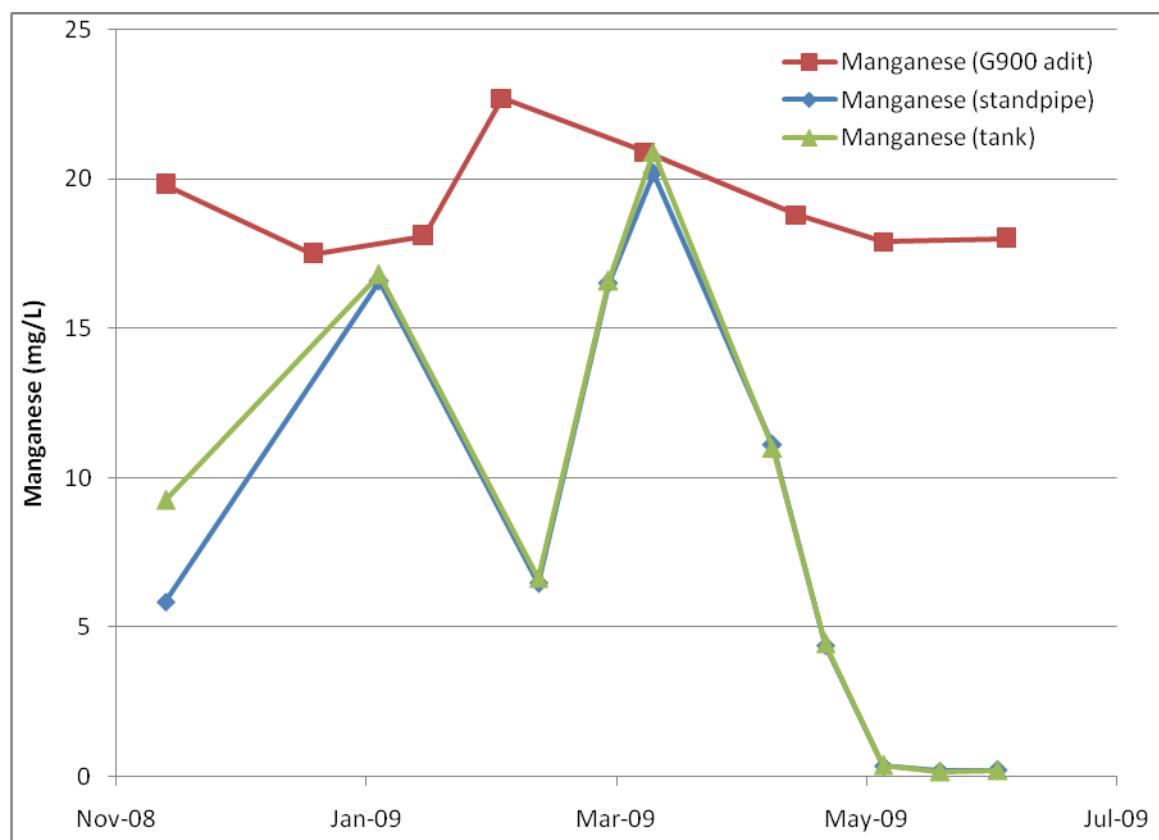


FIGURE 11. MANGANESE REMOVAL IN THE GALKENO 900 BIOREACTOR, MONTHLY SAMPLES FROM OFFSITE COMMERCIAL LAB.

3.2.8. Nickel

Nickel concentrations declined approximately 80% (0.2 mg/L reduced to 0.04 average of last 2 months) during passage through the bioreactor (Figure 12).

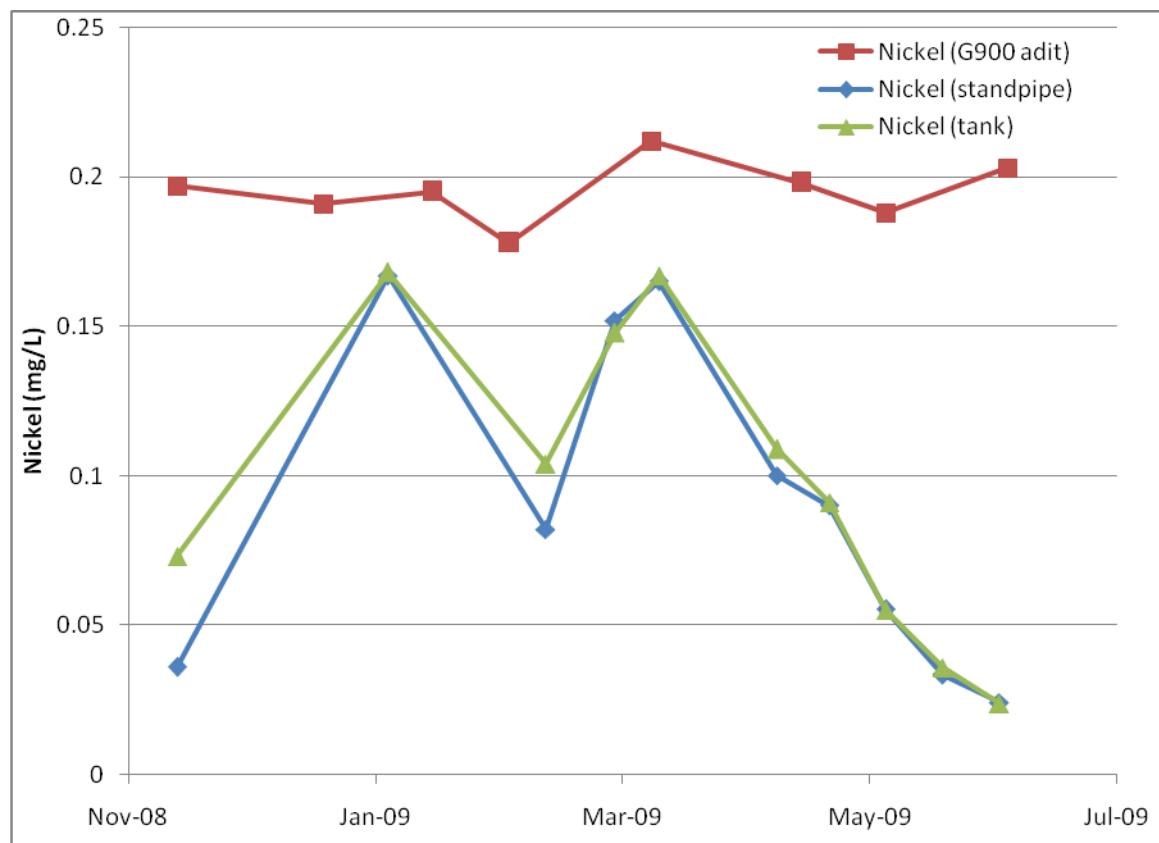


FIGURE 12. NICKEL REMOVAL IN THE GALKENO 900 BIOREACTOR, MONTHLY SAMPLES FROM OFFSITE COMMERCIAL LAB.

3.2.9. Major Cations

Conservative elements show less than 10% change during passage through the bioreactor, including calcium, magnesium, silica, sodium and strontium. These data (Table 1) indicate that dilution is not a significant factor causing metal removal in the reactor in the last few months. The minor amount of calcium removal may indicate its participation in a carbonate precipitation phase in the reactor.

4. METALS REMOVAL MECHANISMS

The formation of metal precipitates in bioreactors has been extensively studied. One “reversible” mechanism often attributed to removal of metals is sorption to organic matter. Because only coarse rock was used as a solid substrate, this mechanism can be dismissed as relevant for the bioreactor performance.

Two classes of metals removal can be broadly described from this preliminary data. In general, metals that showed substantial removal throughout the test include arsenic and iron. Other metals showed initial reduction beginning in January-February when reducing conditions began to be observed in the bioreactor, then removal efficiency was reversed during the siphoning incident, and then the best efficiency was achieved in the last two months when sulfate reducing conditions became apparent in the reactor. Metals in this latter category include zinc, manganese, and trace metals antimony, cadmium, cobalt, and nickel.

Because the products of the sulfate reduction reaction include both sulfide and bicarbonate alkalinity, it is possible that one product or the other is a primary reactant in the precipitation of these metals. Metals that readily form very insoluble sulfides include antimony, arsenic, cadmium, cobalt, iron, nickel, and zinc. Thus it is at least a likely candidate removal mechanism for these metals. As noted in the discussion of both iron and manganese results, the oxides, carbonates, and sulfides formed with these metals are themselves efficient at sorptive removal of trace metals. However, the sulfide removal mechanism is a preferred mechanism when both mechanisms are present because sulfide forms stronger complexes and more insoluble precipitates.

Now that the bioreactor has achieved some level of metal removal capacity, several tests will be undertaken to enhance our understanding of how the bioreactor performance can be maximized. In these tests the results may also help us understand the mechanisms of metal removal even better.

The planned tests for the 2009-2010 work plan will include the following:

- Dye tracer study, which will help evaluate the current residence time in the bioreactor, the amount of short circuiting or dead zones in the bioreactor, and the reactive volume in the reactor.
- Increased dosing of the organic carbon substrate into the reactor until residual organic carbon levels (TOC) in the reactor discharge is over 10 mg/L, or until 2 mg/L residual sulfide is in the reactor discharge. This will determine the theoretical minimum metals concentrations that can be achieve in the reactor. This increased loading rate of substrate will also help maximize the microbiological activity for the step test.
- A step test, where the adit discharge addition to the bioreactor is increased in 2 month increments until metals removal is not effective.
- Metals removal as a function of water temperature will be continuously assessed, as will the bioreactor physical performance during the wintertime months.

These tests will be largely completed in the 2009-2010 work year.

Some scientific papers that may help explain some of the metals removal mechanisms in the bioreactor include the following:

- Stahl and James (1990) “Zinc Sorption by Manganese-Oxide-Coated Sand as a Function of pH” (Soil Science Society of America Journal, vol 55, pgs 1291-1294) evaluates sorption of zinc to manganese oxides coating sand particles. Key findings that relate to Keno include the observation that at low pH, the zinc was primarily in an exchangeable form, but at higher pH, the zinc was primarily in a non-exchangeable form. The mechanisms proposed to account for the nonexchangeable retention of Zn at pH greater than 7 (which is typical for the bioreactor) on oxide-coated sand surfaces were hydrolysis of the Zn followed by chemisorption to the oxide surface. This is a very stable form of storage of zinc, not readily reversible.
- Negra et al, 2005 “Soil Manganese Oxides and Trace Metals: Competitive Sorption and Microfocused Synchrotron X-ray Fluorescence Mapping (Soil Science Society of America Journal, vol 69, pgs 353-361). Manganese oxides have been found to specifically adsorb weakly hydrated cations, commonly in the order of preference Pb > Cu > Mn > Co > Zn > Ni, and their sorption is still strong even in acidic conditions. In neutral pH conditions associated with the bioreactor, the sorption to manganese oxides and their conversion to stable manganese oxide nodules is a possible permanent sink for trace metals.
- Podda et al, 2000, titled “Heavy Metal Coprecipitation with Hydrozincite [$\text{Zn}_5(\text{CO}_3)_2(\text{OH})_6$] from Mine Waters Caused by Photosynthetic Microorganisms” (Applied and Environmental Microbiology, vol 66, pgs 5092-5098) describes the significance of hydrozincite in attenuating zinc and other heavy metals in a stream environment, where 92% zinc removal was observed in a particular stream reach, and hydrozincite was documented as the key precipitate accounting for this significant attenuation. The inputs of alkalinity from natural and photosynthetic sources substantially enhanced the process; in a similar way the bioreactor producing alkalinity may make this attenuation mechanism significant in the bioreactor.
- Labrenz et al (2000) “Formation of Sphalerite (ZnS) Deposits in Natural Biofilms of Sulfate-Reducing Bacteria” (Science, vol 290, pgs 1744-1747) showed that an accumulation of zinc as a sphalerite mineral (ZnS) in biofilms can cause zinc attenuation from liquid to solid phase by a factor of 10^6 . Where organic carbon is readily available, such as in the bioreactor, and sulfate is readily available, sulfate reduction as a mechanism for zinc precipitation in the bioreactor is a likely mechanism.

Based on these references, the precipitates in the bioreactor are likely to be stable as long as they remain undisturbed. The stability of metal-oxide associated zinc, both for iron oxides and manganese oxides, is also good at neutral to alkaline pH which will be associated with pore waters associated with the bioreactor. The zinc sulfide formation in the bioreactor and the precipitation of carbonate minerals associated with the zinc sulfide will enhance its permanence. The permanence of the zinc and other trace metals precipitates will be specifically assessed at the completion of the bioreactor operation.

5. BIOREACTOR CONSTRUCTION PHOTOS



FIGURE 13. SHOWS LINER AND INITIAL LOADING OF COARSE STREAMBED (PLACER) ROCK INTO THE LINED REACTOR.



FIGURE 14. SHOWS LINER AND INITIAL LOADING OF COARSE STREAMBED (PLACER) ROCK INTO THE LINED REACTOR.



FIGURE 15. PLACEMENT OF ROCK IN REACTOR. NOTE LINER BAFFLE ON THE LEFT, DRAINPIPE IN THE CENTER BOTTOM.



FIGURE 16. PLACEMENT OF ROCK WITHIN BIOREACTOR. NOTE SAMPLING STANDPIPE IN CENTER OF PICTURE.



FIGURE 17. GEOTEXTILE PLACEMENT PRIOR TO COVER MATERIAL PLACEMENT.

TABLE 1. DISSOLVED CONSTITUENT CONCENTRATIONS FOR FIRST 8 MONTHS BIOREACTOR OPERATION.

Station	Sample	Al-D	As-D	Sb-D	Ba-D	Cd-D	Ca-D	C-TOC	Co-D	Hard-D	Fe-D	Li-D	Mg-D	Mn-D	Ni-D	P-D	K-D	Si-D	Na-D	Sr-D	S-D	SO4-D	U-D	Zn-D	Sulphide
Name	Date	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mgCaCO3/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
KV-31	11/13/2008	0.022	0.0806	0.0034	0.007	0.00213	359		0.02666	1040	1.82	0.053	36	19.8	0.197	<0.01	0.6	3.54	1.6	0.466			0.0084	6.28	
KV-31	12/19/2008	0.015	0.0864	0.0032	0.009	0.00138	398		0.0296	1120	1.93	0.069	31.9	17.5	0.191		0.6	3.75	1.6	0.449	324		0.0095	5.91	
KV-31	1/15/2009	0.01	0.0903	0.0047	0.008	0.00139	413		0.0276	1020	2.02	0.067	33.1	18.1	0.195		0.7	3.9	2.8	0.467	331		0.0099	6.68	
KV-31	2/3/2009	<0.005	0.0705	0.0024	0.007	0.00129	369		0.0238	1060	2.01	0.054	34.4	22.7	0.178	<0.01	0.8	3.39	1.6	0.487	369		0.0089	6.44	
KV-31	3/10/2009	<0.005	0.0809	0.0033	0.008	0.00126	328		0.0281	959	1.69	0.054	33.8	20.9	0.212	<0.01	0.6	3.39	1.5	0.494	284		0.009	6.82	
KV-31	4/16/2009	0.006	0.0748	0.0026	0.008	0.00148	437		0.0255	1240	1.9	0.06	37.7	18.8	0.198	<0.01	0.73	4.35	1.87	0.463	380		0.0095	6.41	
KV-31	5/7/2009	0.005	0.068	0.0026	0.0084	0.0014	422		0.025	1210	1.85	0.057	39	17.9	0.188	<1	4.11	2	0.453	365		0.00937	6.07		
KV-31	6/6/2009	0.014	0.0687	0.0024	0.0079	0.0016	418		0.0273	1210	1.66	0.057	39	18	0.203	<1	4.28	2	0.449	371		0.00938	6.29		
Bio-pipe	11/13/2008	0.006	0.0021	0.0018	0.041	0.00348	349	108	0.0034	1050	0.026	0.03	44.1	5.85	0.036	<0.01	1.6	3.79	2.7	0.493		844	0.0152	0.78	<0.005
Bio-pipe	1/4/2009	0.01	0.0051	0.0024	0.017	0.00232	408	1.1	0.0196	1200	0.02	0.061	33.1	16.6	0.167	<0.05	0.8	3.84	1.8	0.484	329	1460	0.0104	5.65	<0.005
Bio-pipe	2/12/2009	<0.005	0.0016	0.0016	0.015	0.00206	414	240	0.0017	1200	0.02	0.042	41.4	6.47	0.082	<0.01	0.8	3.55	1.8	0.438	319	989	0.0087	2	<0.005
Bio-pipe	3/1/2009	<0.005	0.0047	0.0016	0.014	0.00215	413	35.9	0.0129	1200	0.02	0.053	41.1	16.5	0.152	<0.01	0.8	3.81	1.7	0.461	308	925	0.009	4.36	<0.005
Bio-pipe	3/12/2009	<0.005	0.0034	0.0018	0.02	0.00261	346	7.8	0.0107	1020	0.03	0.048	37.8	20.2	0.165	<0.01	0.8	3.56	1.6	0.519	298	977	0.0119	3.96	<0.005
Bio-pipe	4/10/2009	<0.005	0.0013	0.0014	0.017	0.00257	408	2.5	0.00214	1200	<0.01	0.042	45.2	11.1	0.1	<0.01	1.1	4.37	2.1	0.449	323	152	0.0103	2.77	<0.005
Bio-pipe	4/23/2009	0.005	0.0015	0.0014	0.019	0.00234	413	2.4	0.0008	1190	0.014	0.047	39.3	4.39	0.09	<0.01	0.95	4.35	1.85	0.459	354	840	0.0109	2.06	0.007
Bio-pipe	5/7/2009	<0.004	0.0014	0.0006	0.0183	0.001	408	2	0.0001	1190	<0.02	0.043	40	0.358	0.0553		<1	4.19	2	0.444	353	940	0.011	1.01	0.005
Bio-pipe	5/21/2009	<0.004	0.0016	<0.0004	0.0165	0.0005	383	2.4	0.0002	1110	0.067	0.037	37	0.178	0.0333		<1	4.2	2	0.425	328	970	0.0114	0.597	<0.005
Bio-pipe	6/4/2009	0.006	0.0016	0.0005	0.0216	0.0006	402	3.1	0.0002	1180	<0.02	0.042	42	0.212	0.0241		1	4.42	2	0.471	348	930	0.0127	0.553	0.006
Bio-tank	11/13/2008	0.007	0.0211	0.0026	0.032	0.00314	355	77.6	0.00916	1060	0.53	0.04	42.4	9.26	0.073	<0.01	1.3	3.78	2.4	0.511		890	0.014	1.909	<0.005
Bio-tank	1/4/2009	<0.005	0.0166	0.002	0.016	0.00209	411	<0.5	0.0199	1150	0.36	0.061	33.3	16.8	0.168	<0.05	0.8	3.85	1.8	0.483	331	1470	0.0105	5.83	<0.005
Bio-tank	2/12/2009	<0.005	0.0017	0.0017	0.016	0.00209	429	242	0.00192	1250	0.01	0.042	43.1	6.64	0.104	<0.01	0.8	3.75	1.8	0.48	327	908	0.0102	2.46	<0.005
Bio-tank	3/1/2009	<0.005	0.0113	0.0017	0.012	0.0019	411	36.1	0.0129	1190	0.24	0.048	40.7	16.6	0.148	0.02	0.8	3.66	1.7	0.45	306	894	0.0095	4.25	<0.005
Bio-tank	3/12/2009	<0.005	0.0034	0.0018	0.018	0.00284	367	8.1	0.0104	1080	0.04	0.05	39.9	20.9	0.167	<0.01	0.9	3.73	1.7	0.52	342	960	0.0114	4.23	<0.005
Bio-tank	4/10/2009	<0.005	0.0016	0.0015	0.016	0.00262	376	1	0.0024	1100	<0.01	0.047	40.6	11	0.109	0.01	1	3.9	1.8	0.435	268	156	0.0103	2.88	<0.005
Bio-tank	4/23/2009	0.002	0.0019	0.0015	0.017	0.00208	414	1.9	0.0009	1200	0.015	0.046	39.7	4.45	0.091	<0.01	0.95	4.33	1.85	0.452	355	860	0.0108	2.12	<0.005
Bio-tank	5/7/2009	0.009	0.0017	0.0005	0.0164	0.0009	407	1.7	0.0001	1180	0.032	0.042	40	0.374	0.0551		<1	4.14	2	0.439	351	1000	0.011	1.04	0.007
Bio-tank	5/21/2009	<0.004	0.0024</td																						