OVERCOMING THE OBSTACLES OF OPERATING A BIOCHEMICAL REACTOR AND AEROBIC POLISHING CELL YEAR ROUND IN CENTRAL MONTANA[1]

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Abstract: A demonstration-scale passive treatment system (PTS) including a biochemical reactor (BCR) and an aerobic polishing cell (APC) has been constructed at a historic gold mine in Central Montana. This site provided the challenge of being located where the frost depth is over four feet and temperatures dropped to negative 40˚ F in the winter of 2007-2008. The demonstration-scale PTS, including the APC, was operated through the winter. This paper presents the results of the testing as well as the special consideration and precautions taken to ensure the PTS could function properly year round.

The BCR uses a mixture of organic components including wood chips, sawdust, hay, limestone, manure, and crushed basalt to remove constituents of concern (COC), including thallium, selenium, zinc, and nitrate from the mining influenced water (MIW) at the site. As the MIW passes through the BCR, a suite of biological and chemical reactions (biological reduction, metal sulfide precipitation, metal hydroxide precipitation, adsorption, etc.) combine to reduce the COC concentrations in the effluent. Over the first 14 months of BCR operation thallium was removed at >99%, selenium was removed at >99% until BCR maintenance disturbed the substrate in the fall of 2008, and zinc and nitrate were removed to non detect levels throughout. The BCR has operated successfully through two winters where temperatures reached levels as low as -40˚ F for up to weeks at a time.

Due to the natural degradation of the organic substrate mixture used in the BCR, the water exiting the cell has elevated levels of organic matter as well as manganese, iron, and arsenic. These constituents are removed in an APC, which is comprised of a series of ponds that contain vegetation and large surface area to promote aeration of the water. As oxygen is introduced to the water, the biochemical oxygen demand, manganese, iron, and arsenic are changed from dissolved to particulate form and either settle or are filtered out by the vegetation in the APC. The APC has yet to operate through a full winter without retrofits and upgrades.

Additional Key Words: biochemical reactor, aerobic polishing cell, thallium, selenium, mining influenced water, winter operation

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Introduction

Active and inactive mine sites are often required to perform water treatment to remove heavy metals and other constituents of concern (COCs) prior to discharging water. Traditional water treatment can be expensive and impractical at some sites due to excessive energy, manual labor, and operation and maintenance (O&M) requirements. Passive treatment has emerged as a way to treat such waters inexpensively by requiring minimal amounts of O&M and little to no external energy. One passive treatment technology that has been developed over the last twenty years is the biochemical reactor (BCR), also known as a sulfate reducing bioreactor (SRBR) (Postgate, 1979, Wildeman, et al., 1993, Gusek, 2000, Gusek et al., 2000, Gusek, 2001, Busler et al., 2002, Thomas and Romanek, 2002, Seyler et al., 2003, Gusek et al., 2006, Faulkner et al., 2007). As its name would suggest, a BCR treats water by way of biological and chemical reactions (pH adjustment, hydroxide precipitation, metal sulfide precipitation, and adsorption). A BCR uses a combination of organic substrate materials and microbial activity to remove heavy metals, other COCs, and stabilize pH in mining influenced water (MIW) (Wildeman, et al., 1993). Additionally, a BCR adds hardness, alkalinity, and organic matter to the MIW, all of which are beneficial to overall water quality and aquatic life (Blumenstein et al., 2006).

A confidential historic gold mine in Montana is using passive treatment in the form of a BCR to remove Tl, Se, and NO_3^- from the MIW generated on site (Blumenstein et al., 2008). In the reducing state of the BCR, sulfide is produced via sulfate reduction and it is believed that Tl precipitates out as an insoluble metal sulfide (TlS, Tl_2S, and Tl_2S_2) (Nriagu, 2003). Additionally, the reducing conditions in the BCR will reduce the Se present as selenate (Se^{+6}) to selenite (Se^{+4}) and then to elemental Se^0 (Gusek et al., 2008). Because little was known regarding the treatment and preferential removal of Tl, a three month bench-scale test using a variety of different organic substrate mixtures was conducted to determine how Tl could best be removed in a BCR. After steady state conditions were reached in the BCR, bench-scale testing demonstrated ≥ 99% removal of T, Se and other heavy metals (Zn, Cu, Fe, etc.). Guided by the bench-scale testing results, a demonstration-scale passive treatment system (PTS), which is half of the size of a full-scale system, was constructed and has been operational since November 2007.

The demonstration-scale PTS consists of a BCR, an aerobic polishing cell (APC), and all the requisite pipes and valves to run the system with a gravity feed. This paper discusses the results of the demonstration-scale PTS over its first year of operation and the challenges encountered in keeping the BCR and APC running year round, including exposure to temperatures as low as -30˚ F, in a central Montana winter.

Demonstration-Scale BCR and APC Passive Treatment System

The positive overall results in the bench-scale phase of testing supported the development of a demonstration-scale system which would become a modular component of a full-scale system. For this site, the demonstration-scale system was designed to handle half of the potential maximum MIW flow. The design of the demonstration-scale PTS included a BCR cell for primary water treatment and an aerobic polishing cell (APC) for secondary treatment and polishing prior to discharge.

Demonstration-Scale Methods and Design

The demonstration BCR substrate mixture was selected to mimic BCR bench Cell 3, based on the bench-scale BCR test results (Blumenstein, 2008). BCR bench Cell 3 contained magnetite sacrificial media and performed well during the bench study. magnetite ore as the sacrificial media (BCR Cell 3).

Unfortunately, the source of the magnetite ore used in the bench-scale testing was unavailable at the time of material procurement for construction of the demonstration-scale PTS. Consequently, crushed basalt was substituted for the magnetite ore in order to preserve an already-compressed construction schedule. Basalt was chosen because of its chemical composition and its availability at the time of construction. The actual substrate recipe used in construction of the demonstration-scale BCR system is displayed in Table 1.

Table 1. Cell mixture for demonstration-scale BCR cell

Material	Proportion by Weight
Wood Chips	46%
Limestone	30%
Hay	10%
Crushed Basalt	4%
Animal Manure	10%
Total	100%

An APC was also included in the demonstration-scale PTS design. The APC was added to the PTS to remove BOD, sulfide, Fe, and Mn from the BCR effluent prior to discharge.

The demonstration-scale BCR was designed to handle a nitrate molar removal rate of 0.06 moles/m^3/day of substrate. At this rate, the hydraulic retention time in the BCR is between 7 and 10 days, which is sufficient for Tl (average of 1.2 mg/L) and Se (average of 0.015 mg/L) removal at the concentrations present in the BCR influent water. The bench-scale BCR cells were originally designed to handle a NO_3^- load of 0.03 moles/m^3/day, but the bench-scale BCR cells proved to be able to handle more than twice that while still removing NO_3^-, Tl, and Se to below analytical detection limits during bench testing.

The APC was designed to remove 20 mg/L BOD concentrations to less than five mg/L during normal operating conditions of five gallons per minute (gpm) once fully vegetated. This BOD removal was estimated based on a 0.5 degree Celsius water temperature during winter operation determined via correspondence with Dr. Joe Middlebrooks (Middlebrooks, 2007).

Demonstration-Scale Construction

Permitting clearance issues delayed earthwork on the PTS until September, 2007. The earthwork and compacted fill for the BCR cell were completed by the end of September, and substrate was mixed and placed in the BCR cell during the first week of October. Additional hay was mounded on top of the BCR cell to provide insulation against the cold air and wind in the fast-approaching winter months. MIW was introduced to the BCR cell in the middle of October and allowed to incubate for approximately three weeks. While the BCR cell was incubating, earthwork and construction of the APC began. The BCR incubation was complete and the APC was constructed by early November of 2007.

The BCR cell operation commenced in early November, with the effluent bypassing the APC and being sent directly to the mine site's lower pump back station for recirculation. The APC was bypassed until the BCR cell had flushed-matured such that the BOD was reduced to a reasonable level (< 500 mg/L). At that point, BCR effluent was diverted to the APC for polishing and secondary treatment for removal of any remaining BOD, Fe, and Mn. A process flow diagram of the complete demonstration-scale BCR PTS is shown in Fig. 1.

In addition to bypassing the APC (APC bypass vault), plumbing was installed to enable untreated MIW to be mixed with the BCR effluent water (see Fig. 1). Thus, residual treatment characteristics of the BCR effluent might be put to beneficial use. Bypassing MIW around the BCR cell will prolong the BCR cell life; this portion of the demonstration-scale BCR PTS is identified on Fig. 4 as the mixing vault. It is important to note that the mixing vault is an option for this system because the nitrate discharge limit is < 10 mg/L. Consequently, any nitrate present in the MIW that bypasses the BCR does not need to be removed in the mixing vault. The beneficial treatment in the mixing cell would come from the utilization of any sulfide or low redox conditions present in BCR effluent to precipitate Se, Tl, and any Fe present.

The final component of the demonstration-scale BCR PTS is the aeration cell (Fig. 1). After MIW has been treated by the BCR cell and polished in the APC, it reports to the aeration cell which is a concrete vault (three feet by three feet wide and four feet deep). Here, mechanical aeration can be introduced to the COC-stripped water if it is not adequately oxygenated after passage through the APC. Pipelines (P-1 through P-11) and sampling locations (S) have been called out in Fig. 1.

Preliminary Demonstration-Scale Results

Field Results - Field parameters and flow data were recorded as soon as the BCR cell received MIW on a continuous basis. Field parameters (pH, ORP, temperature, and conductivity) were recorded using HACH and Oakton field meters and probes. Analytical samples were also collected beginning in early January 2008 and sent to Energy Laboratories in Billings, MT for inductively coupled plasma mass spectrometry (ICP-MS) total metals analysis (Method E200.8) and biological biochemical oxygen demand (BOD) (Method A5210 B) and total coliforms (including *Escherichia coli*) (Method A9222 D). This paper provides the field parameters, flow data, and analytical results through early January 2009. Additional field parameters, flow data, and analytical results will be collected and developed over the coming months and will be discussed in detail during the ASMR presentation in June of 2009.

Field parameters were recorded one to two times per week starting in early November, as soon as flow was observed discharging from the BCR cell. Over the first two months of operation, a flushing-maturation process was observed similar to the bench performance. Over the first few pore volumes the demonstration-scale BCR cell received, the effluent pH increased while the oxidation-reduction potential (ORP) and electric conductivity dropped. Plots of the field parameters (pH, Temperature, ORP, Conductivity, and Flow) observed over the first 14 months of BCR cell operation can be found in Fig. 2-6, respectively.

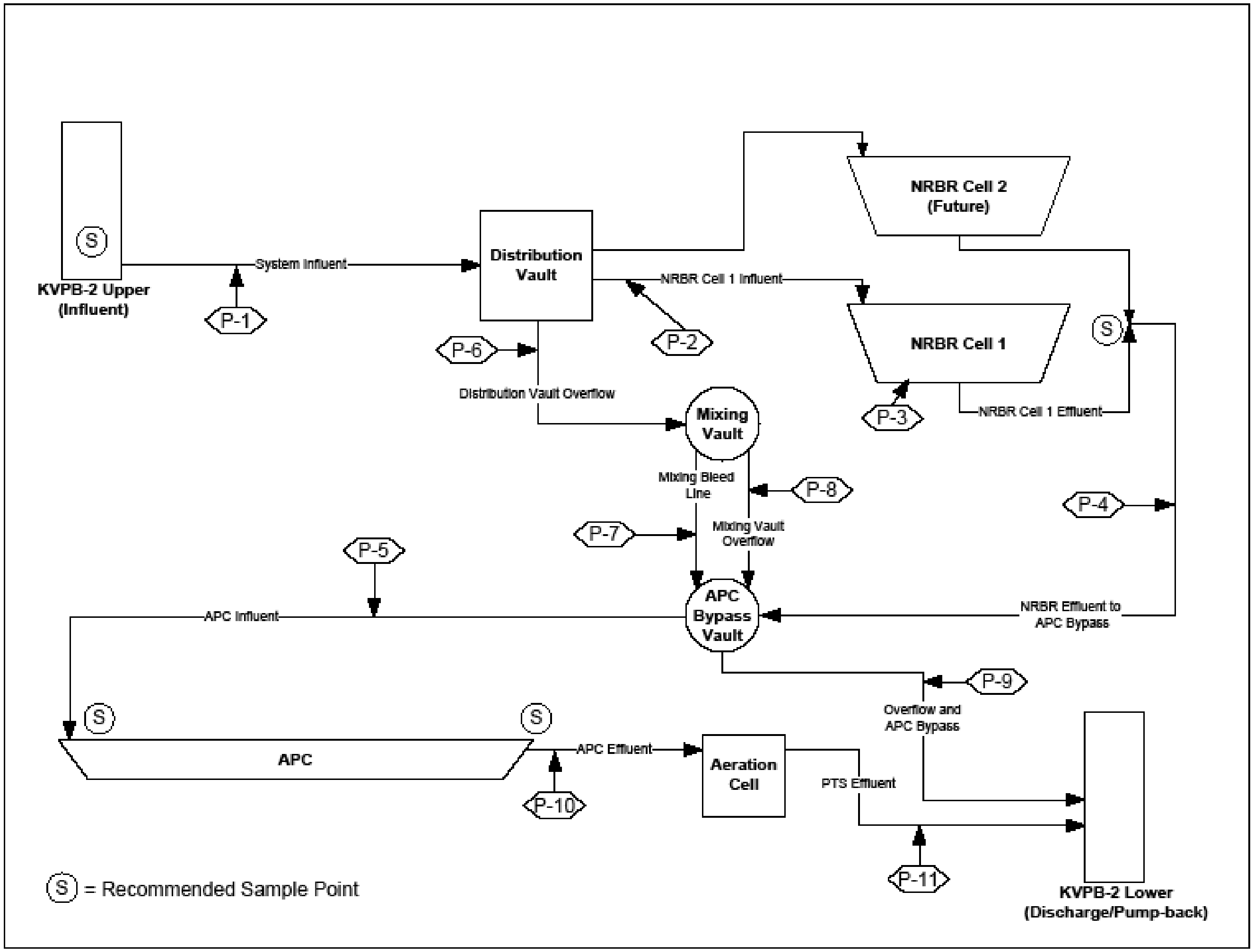

Figure 1. Process flow diagram of the demonstration-scale BCR passive treatment system.

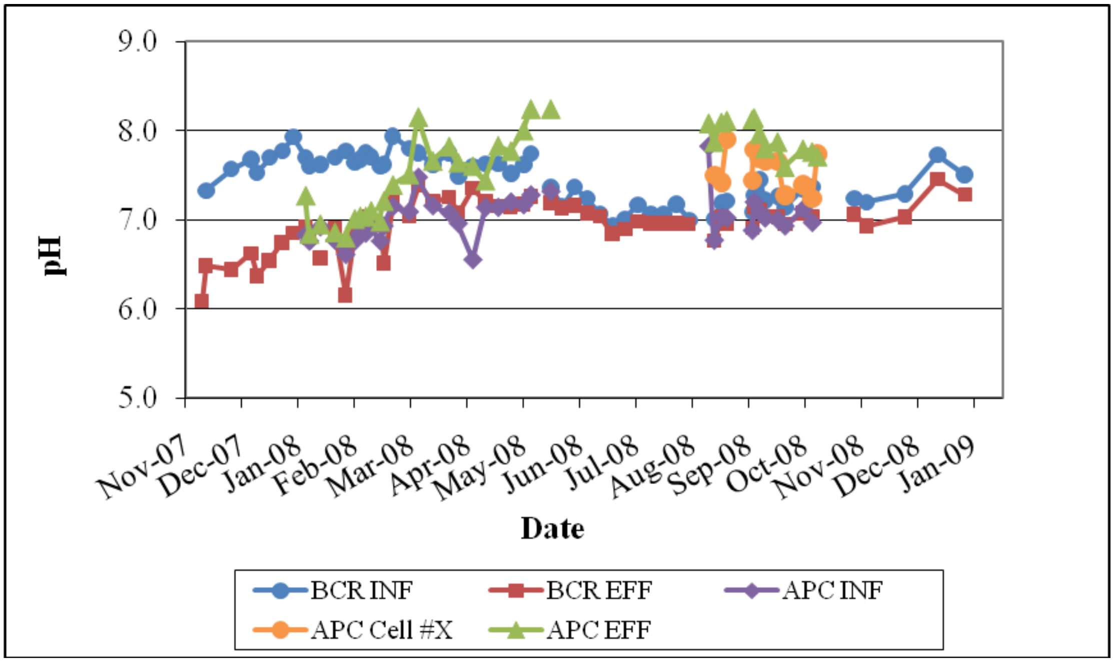

Figure 2 – pH of Demonstration-Scale PTS

As shown on Fig. 2, the post flushing-maturation period BCR effluent pH closely mirrored that of the BCR influent, between 7.0 and 7.5 standard units. When flow was diverted through the APC, the pH increased to levels near 8.0 standard units. All pH values observed have been within the regulatory range of 6.0 – 9.0 standard units.

The temperature of the BCR influent (MIW) and BCR effluent over the first 14 months of PTS operation are displayed in Fig. 3.

The water temperatures ranged from 5˚ - 16˚ C over this time period. Of note is that the BCR effluent temperature was higher than the BCR influent temperature from November 2007 through June 2008, while the reverse was true from July 2008 through January 2009. Despite this inversion of temperatures, the BCR has removed metals effectively throughout the entirety of the first 14 months of PTS operation.

Oxidation-reduction potential (ORP) is one of the most valuable ways to track the relative health of a BCR. BCR conditions are typically anaerobic, so the ORP of a BCR's effluent should be significantly less than that of the influent. In this case, the ORP of the BCR influent is between 0 and 75 mV, whereas the ORP of the BCR effluent is typically less than -150 mV. ORP values for the first 14 months of PTS operation are displayed in Fig. 4.

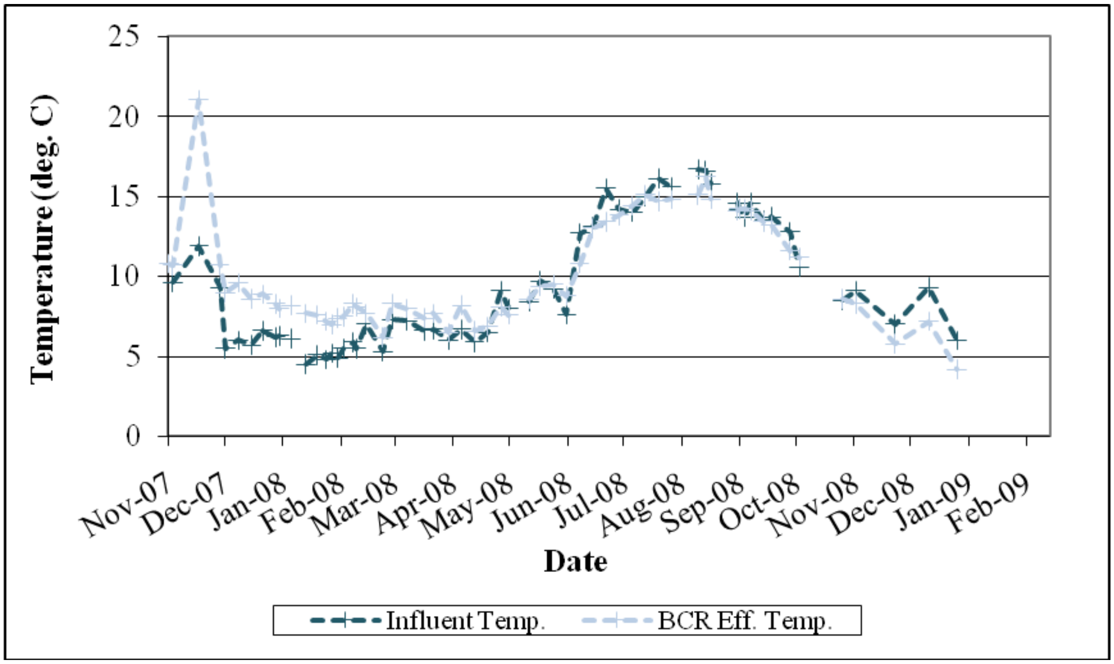

Figure 3 – Temperature of Demonstration-Scale PTS

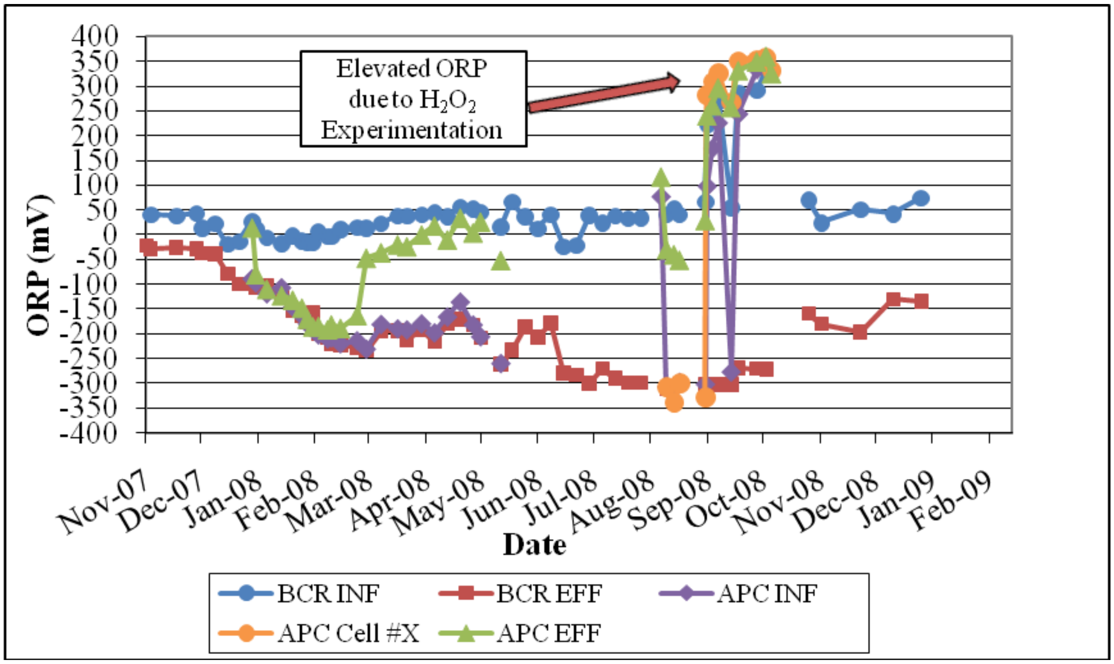

Figure 4 – Oxidation Reduction Potential (ORP) of Demonstration-Scale PTS

Conductivity is shown in Fig. 5. After the BCR matured conductivity in the BCR effluent has been similar to that of the BCR influent.

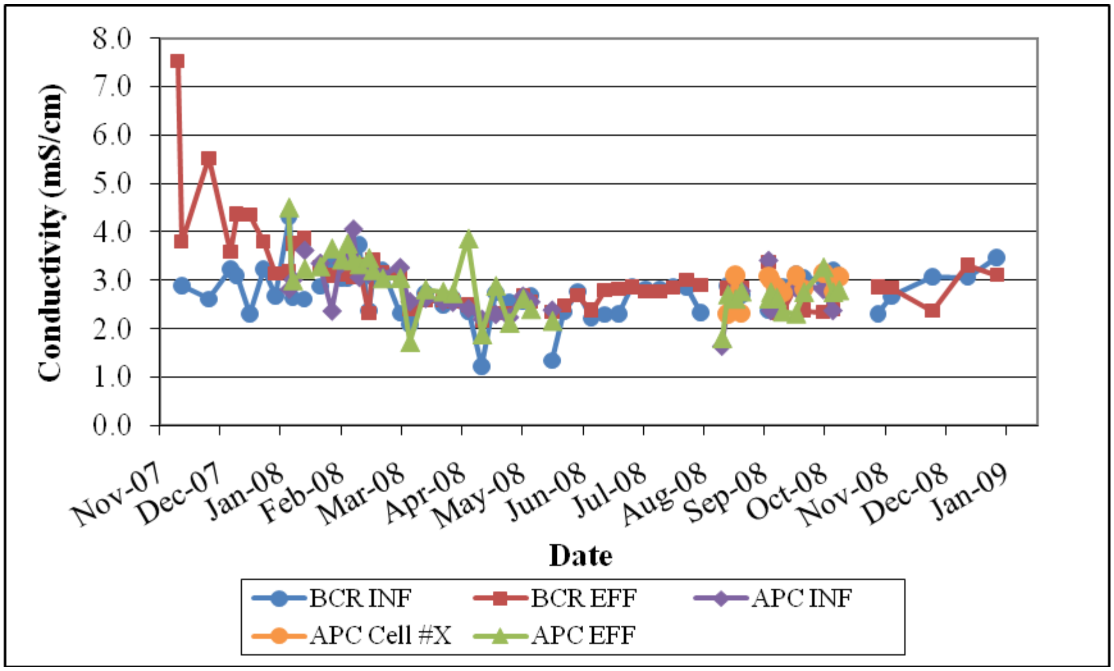

Figure 5 – Conductivity of Demonstration-Scale PTS

The BCR for the demonstration-scale PTS was designed to treat a maximum flow rate of 5 gallons per minute (GPM). Figure 6 displays the MIW flows that the PTS has treated over the first 14 months of operation: With some exceptions, the flow rates have typically been at or below the 5 gpm design rate. During the 2008 spirng runoff period, however, flows ranged from 5 to 10 gpm. Between May and August of 2008, flows were either quite high or the BCR was overloaded (May) or unknown because the flow totalizer was temporarily removed from the PTS (June – August). The totalizer was removed during this period because of an unidentified red moss in the BCR influent water that was restricting the flow into the BCR.

Analytical Results from the BCR – The first samples were sent to the Energy Laboratories (Energy) in Billings, MT for the 2nd January 2008 sampling event. For the first 45 days of analytical sampling, samples were sent to Energy once a week (through 21st February 2008). Subsequently, (from 6th March 2008 through the end of 2008), samples were sent to Energy every other week. Analytical results for the primary COCs: Tl, Se, and NO_3^-, are plotted in Fig. 7 – 9.

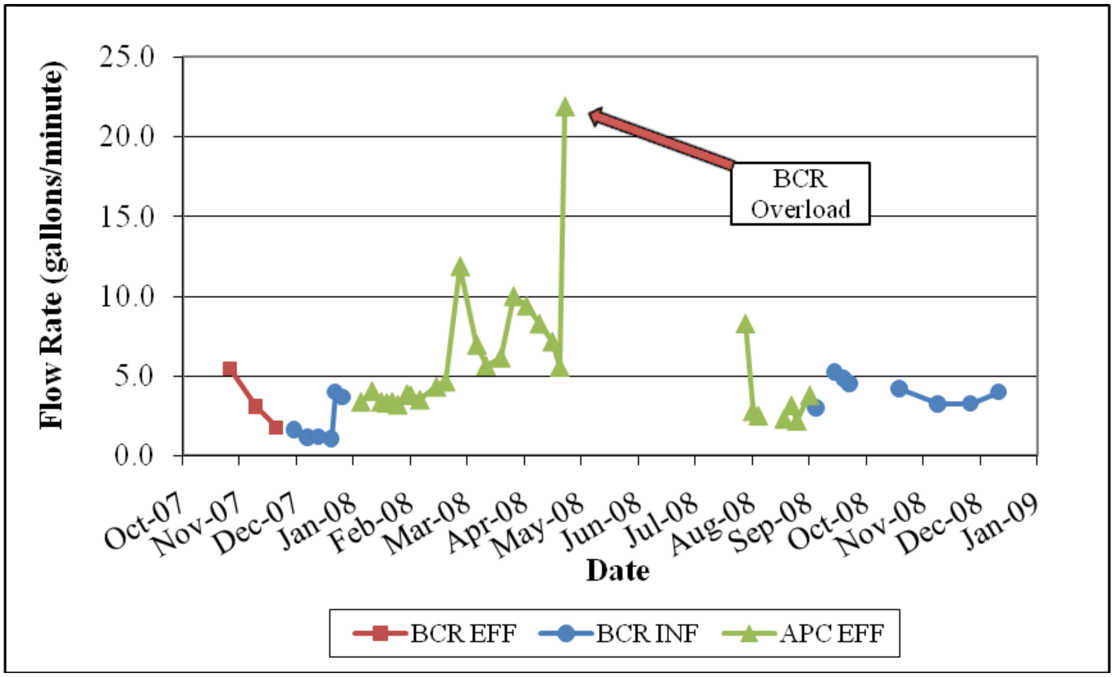

Figure 6 – Flow Rate of Demonstration-Scale PTS

The average Tl concentration in the BCR influent has been 1.25 mg/L over the first 14 months of operation, and it has been reduced to an average concentration of 0.007 mg/L in the BCR effluent in that time. The average BCR effluent concentration value was significantly influenced by the effects of two upset events in the BCR cell. The first upset event occurred when the flow rate increased to a level of 21 gpm, or four times the design flow rate, in July 2008. As the flow rate dropped, the Tl concentrations in the BCR effluent dropped correspondingly, as displayed in Fig. 7. Thallium removal efficiency was still about 90% during this upset event.

The second upset event occurred in October of 2008 when excess substrate was removed from the top of the BCR cell. The substrate was removed using a bull dozer on tracks, but the removal process still upset the BCR to the point where a trace amount of Tl was seen in the BCR effluent. Other than those two upset events, the Tl concentration in the BCR effluent has been below the Energy ICP-MS detection limit of 0.001 mg/L (1.0 µg/L) since June of 2008. Excluding the data from the two upsets, the average Tl concentration in the BCR effluent would have been 0.002 mg/L since operations commenced.

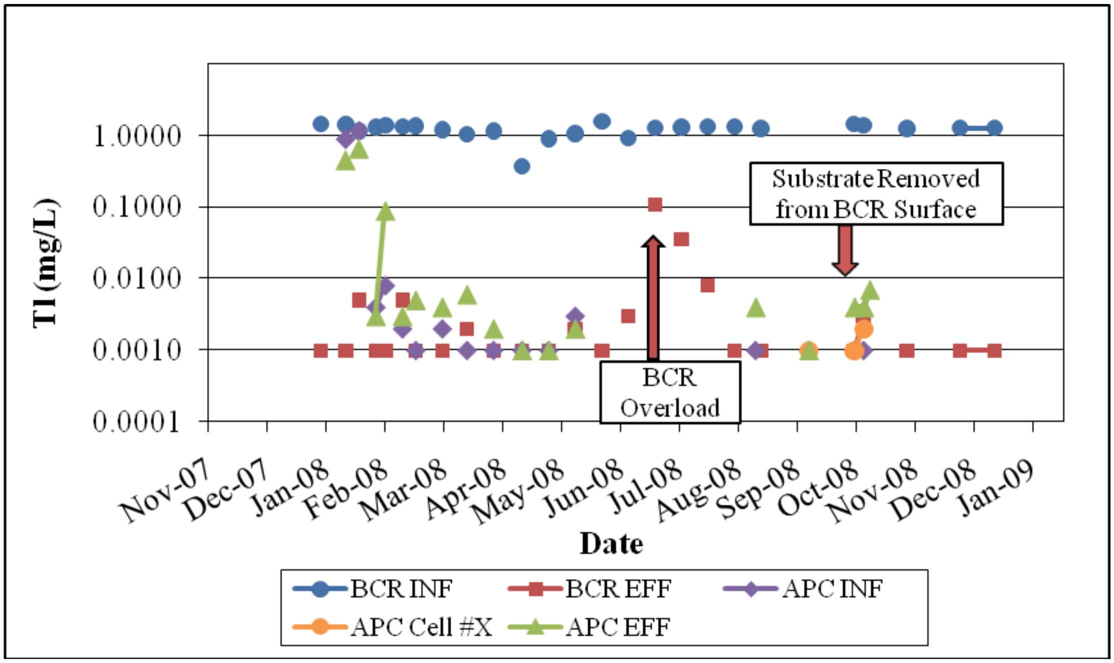

Figure 7 – Thallium Concentrations in the Demonstration-Scale PTS

The average Se concentrations in the BCR influent and effluent were 0.013 mg/L and 0.001 mg/L, respectively, during the first 14 months of operation. The only time that Se has been observed in the BCR effluent was after the substrate removal event previously described. After the excess substrate was removed, it took nearly two months for the Se that had been mobilized to flush out of the BCR to the point that the cell exhibited lower levels of Se in the effluent than in the influent.

It is suspected that the Se was mobilized because of the way it is probably removed in a BCR and the way the excess substrate was removed. As with similarly-designed BCRs, Se is probably removed from solution and immobilized by the biological reduction of the Se present as selenate (Se^{+6}) to selenite (Se^{+4}) and then to elemental Se^0 (Gusek et al., 2008). When this BCR was being prepared for substrate removal to correct an overbuilt situation, the water level was lowered to one foot or more below the surface of the substrate. Lowering the water level caused significant oxidation of the substrate that had typically been reducing and had is suspected to have sequestered Se^0. As the substrate and Se were oxidized, the Se^0 converted back to selenite or selenate and was subsequently flushed out of the BCR. After the excess substrate was removed and anaerobic conditions returned in the BCR, the BCR once again exhibited Se removal. Selenium concentrations throughout the first 14 months and the substrate removal event are plotted on Fig. 8.

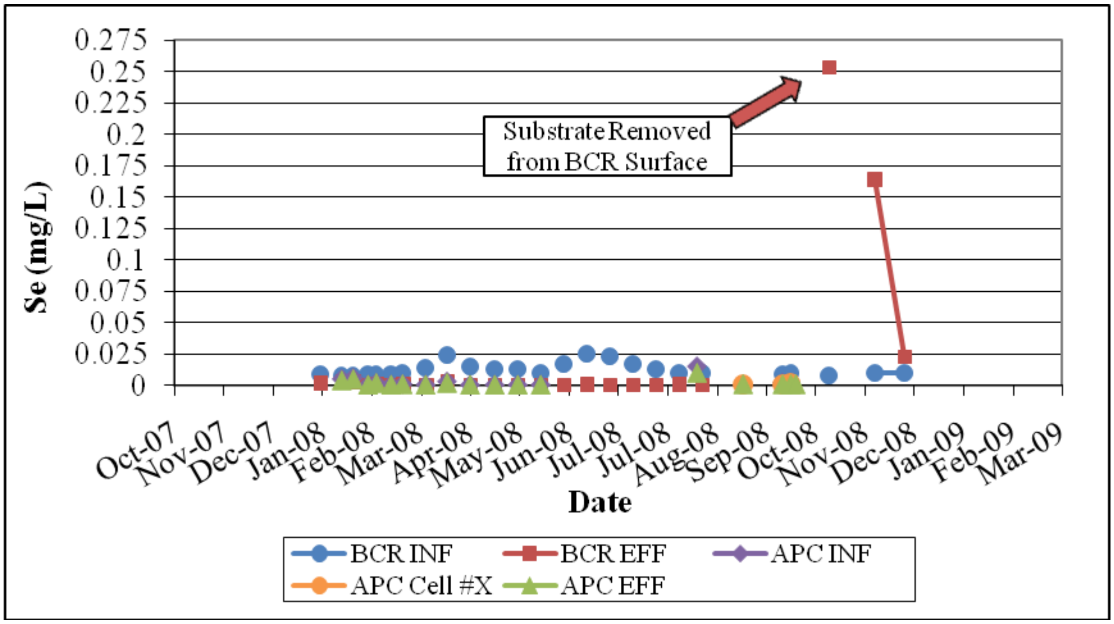

Figure 8 – Selenium Concentrations in the Demonstration-Scale PTS

Average nitrate (NO_3^- as N) concentrations in the BCR influent and effluent were 5.1 mg/L and 0.08 mg/L, respectively, when monitored for over the first 14 months of operation. Nitrate was reduced to nitrite (NO_2^-) and then ammonia (NH_3) or nitrogen gas (N_2) as is passed through the anaerobic BCR. The expected mechanism for NO_3^- removal is denitrification via denitrifying bacteria (*Thiobacillus, Micrococcus denitrificans, and Pseudomonas aeruginosa* among others) (Madigan, 2002). Nitrate was not monitored after July 2008 because it was reasoned that sufficient data had been collected for that parameter to demonstrate that the BCR would reliably remove NO_3^- from the MIW. The analytical data that was collected for NO_3^- is plotted on Fig. 9.

Data from the first 14 months of operating the demonstration-scale PTS at this site have suggest that the BCR is capable of removing Tl, Se, and NO_3^- provided that the cell is not overloaded or disrupted by non-routine BCR cell maintenance activities. If the BCR receives flow four times four times greater than the design value, a breakthrough in Tl should be expected in the BCR effluent. However, a similar Se breakthrough may not occur. If the BCR water level is lowered and the substrate surface is exposed to the atmosphere, significant amounts of Se will likely be mobilized; however, Tl may not be mobilized.

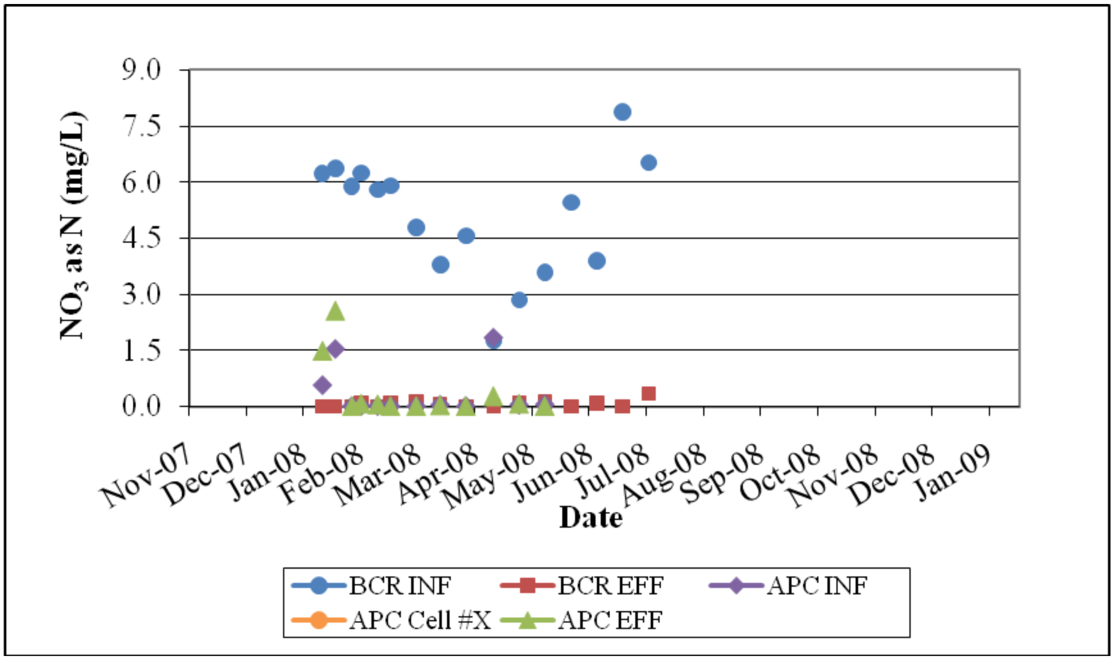

Figure 9 – Nitrate Concentrations in the Demonstration-Scale PTS

Data from these two upset events provide an insight into the mechanisms that may be at work in removing Tl and Se in the BCR. As previously discussed, Tl is most likely removed by forming an insoluble metal sulfide (TlS, Tl_2S, and Tl_2S_2) (Nriagu, 1998). The upset data suggest that a required minimum retention time in the BCR must be met or Tl will not be completely removed from solution. Selenium, on the other hand, precipitates out as reduced elemental Se^0 that may not need as long of the retention time as Tl to be removed. If the substrate where Se^0 is allowed to oxidize, however, the Se will be most likely be easily mobilized and flushed from the BCR cell until anaerobic conditions are re-established.

Combining Se and Tl removal efficiencies into a single value provides an overall measure of system performance during the first 14 months of the demonstration-scale test. Removal efficiencies are calculated by combining the molar metal removal rate of each metal into one factor. For example:

$$\left(\frac{M1INF}{MW} - \frac{M1EFF}{MW}\right) x\ 100 = \ M1\ Molar\ Removal\ Efficiency\ \%,$$

$$\left(\frac{M2INF}{MW} - \frac{M2EFF}{MW}\right) x\ 100 = \ M2\ Molar\ Removal\ Efficiency\ \%,\ and$$

$$\begin{aligned}&Combined\ Removal\ Efficiency\ \%\\ &\qquad = \ M1\ Removal\ Efficiency + \ M2\ Removal\ Efficiency\ \%\end{aligned}$$

Where M1 is the first metal being removed, M2 is the next metal being removed, and MW is the molecular weight of the metal being removed.

Combined Se and Tl removal efficiency was always greater than 99%, with the exception of the two upset conditions. A week by week plot of combined Se and Tl removal is presented in Fig. 10.

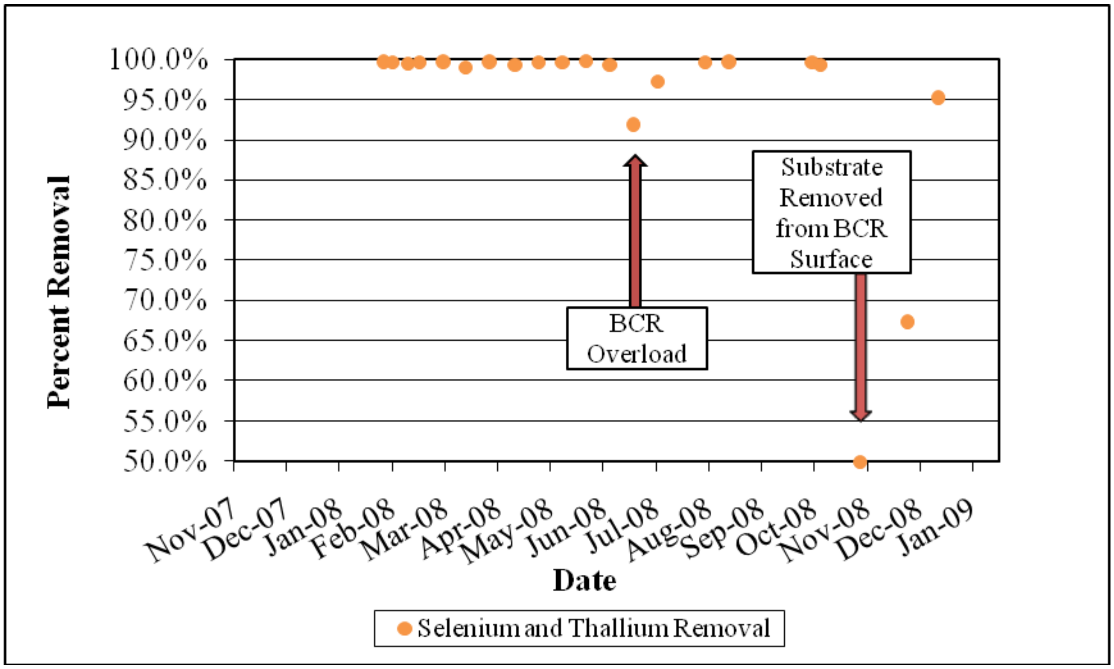

Figure 10 – Selenium and Thallium Concentrations in the Demonstration-Scale PTS

Byproducts from BCR Treatment – When a BCR is working properly, microbes break down the organic substrates that are present in the cell, in this case: wood chips, hay, and animal manure. As the organic matter is decomposed and flushes out of the BCR, elevated levels of biochemical oxygen demand (BOD) are apparent in the BCR effluent. Manganese is not typically removed in the anaerobic BCR, so if it is present in the BCR influent, it will be preserved in the BCR effluent. In short, BCR effluent commonly contains BOD and Mn.

Two uncommon byproducts from this particular BCR cell are As and Fe that have been added to the BCR effluent by one of the substrate components. The most likely source of As contamination in this case is the crushed basalt that was substituted for magnetite as a sacrificial source of Fe. Because the basalt was added in a quick response to a field supply shortfall, it was not possible to fully test the basalt to determine if it had any negative characteristics. Consequently, these four parameters (BOD, Mn, As, and Fe) comprise the secondary COCs that must be removed from the BCR effluent in an APC.

Analytical Results for Secondary COCs – For the currently sized APC to effectively remove the remaining BOD, Mn, and As from the BCR effluent, the BOD concentration must decrease to levels below 30-50 mg/L prior to reaching the APC. At other PTS sites, BOD in BCR effluent has typically dropped to concentrations below 50 mg/L within the first six months of operation. As can be seen in Fig. 11, BOD levels dropped to a range between 100 – 200 mg/L within six months of operation at this site, but the BOD did not decrease further by the 12 month mark, and actually increased slightly in the summer months.

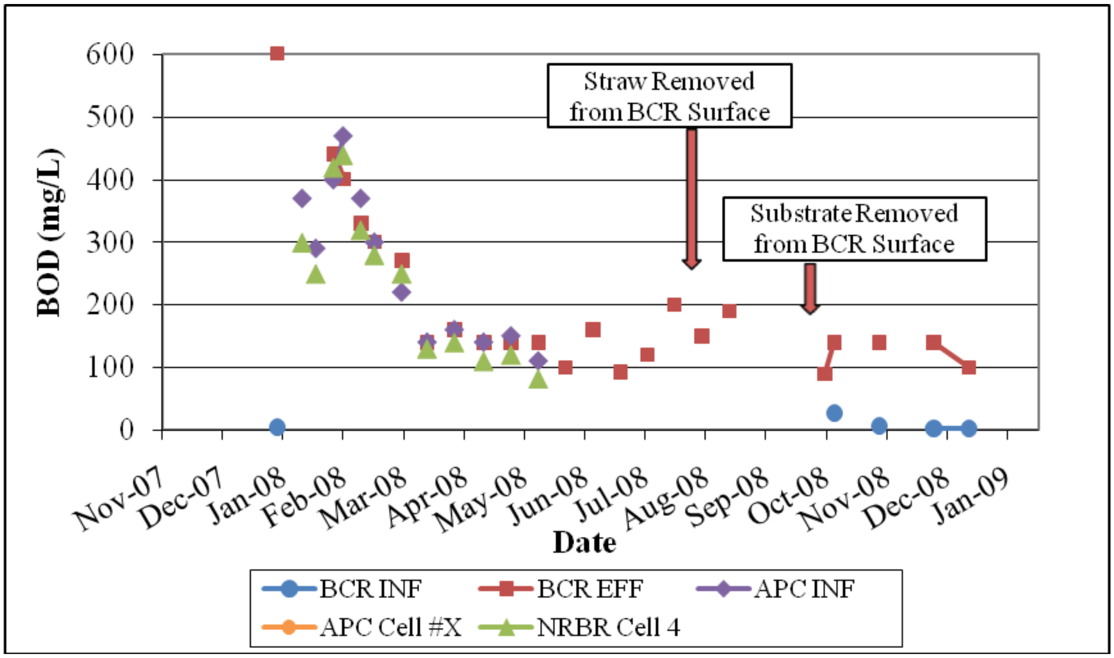

Figure 11 – BOD Concentrations in the Demonstration-Scale PTS

In an attempt to remove any sources of excess BOD from the BCR, straw that had been mounded on top of the BCR as insulation during the first winter of operation was removed in August 2008. Excess substrate was also removed from the top of the BCR in October 2008, as stated earlier in this paper, to ensure that the top of the substrate layer was completely submerged. This ensured that the degradation of organic matter did not occur faster than necessary (which would artificially increase BOD levels). Unfortunately, this meant that the top of the BCR would be exposed to freezing weather in the second winter of operation. As of mid January, 2009, the BCR has successfully operated through an eight day stretch of 0° to -35° F weather. None of the BCR influent or effluent pipes have been heat-traced.

Manganese levels have averaged 0.06 mg/L in the BCR influent during the first 14 months of operation. During that period, they averaged 1.0 mg/L in the BCR effluent. The APC was included in the PTS design to remove any excess Mn present in the BCR effluent, but an APC will not do so until BOD is fully removed from the water. Manganese concentrations throughout the first 14 months of operation are plotted in Fig. 12.

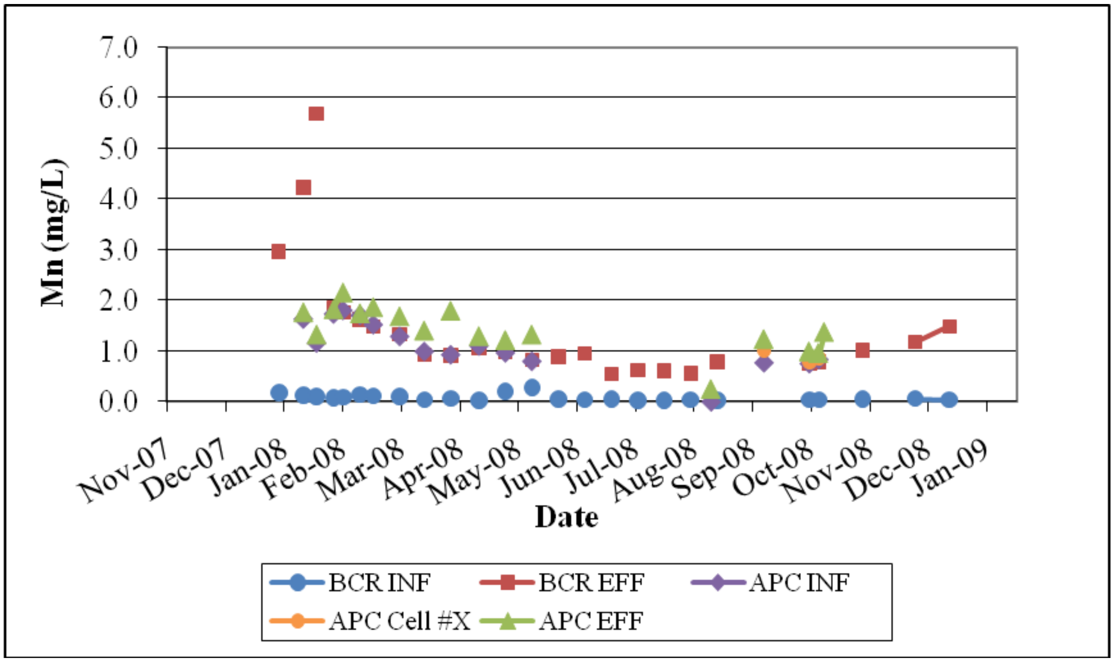

Figure 12 – Manganese Concentrations in the Demonstration-Scale PTS

The final two secondary COCs that will need to be removed in the APC are As and Fe, whose data are plotted in Fig. 13 and Fig. 14, respectively.

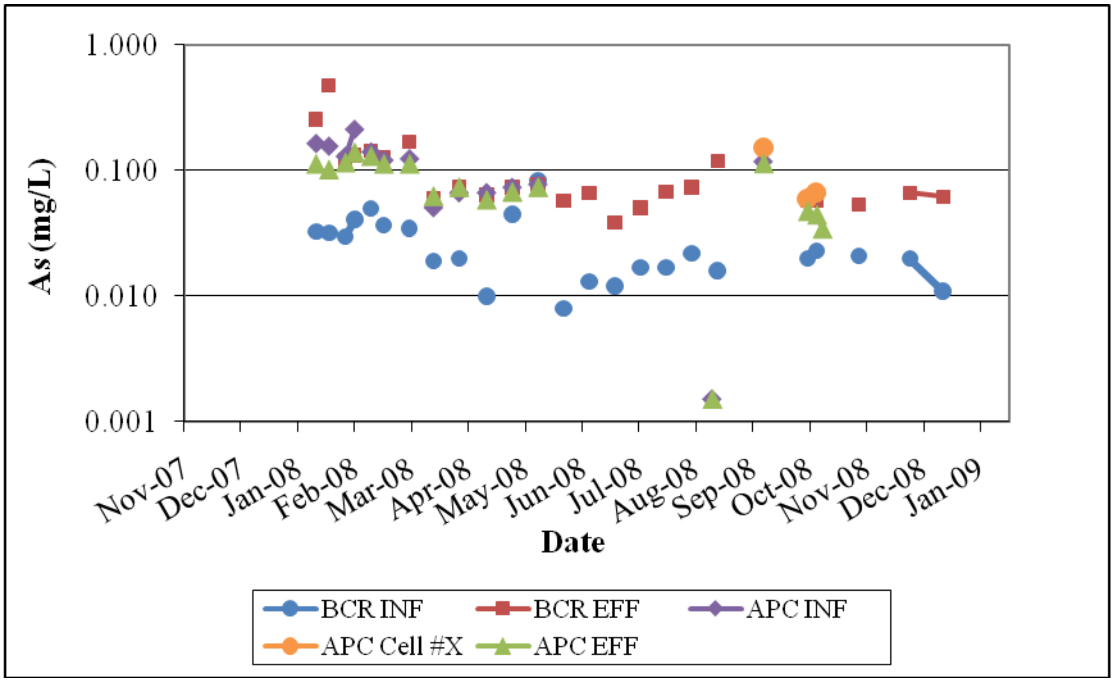

Figure 13 – Arsenic Concentrations in the Demonstration-Scale PTS

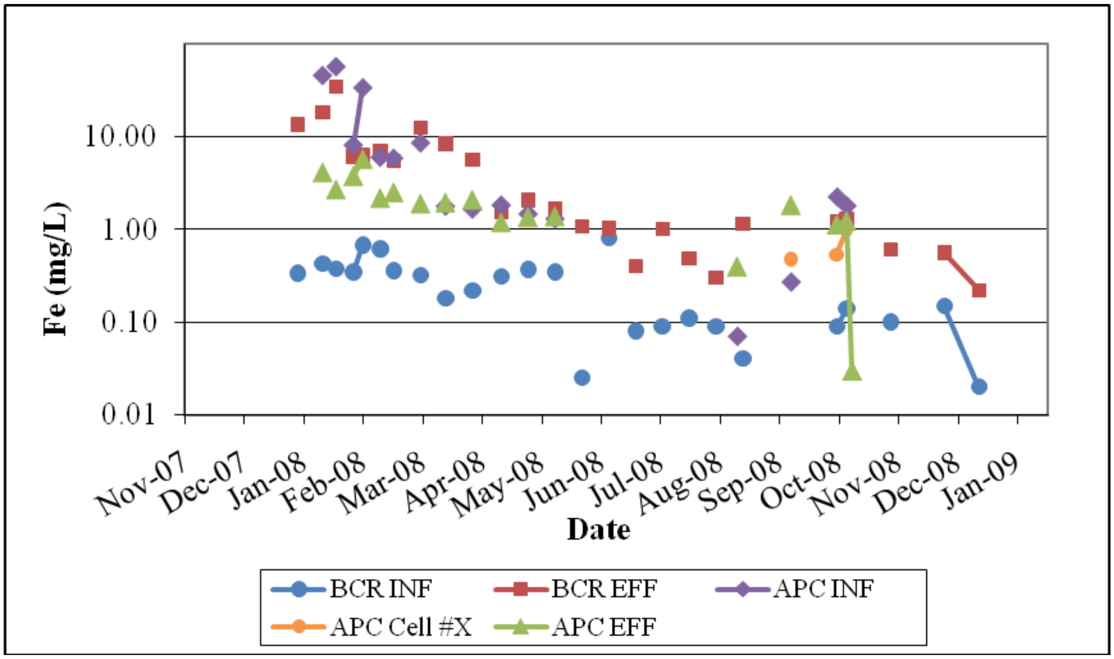

Figure 14 – Iron Concentrations in the Demonstration-Scale PTS

As previously discussed, the basalt in the substrate is the suspected source of the elevated As and Fe concentrations in the BCR effluent. The sacrificial Fe source was added to encourage the co-precipitation of Tl with Fe sulfides in the BCR. Based on the bench testing data, the increase in Fe was expected, but the increase in As was not. This clearly demonstrates why a material should not be used in construction of a BCR unless it has been fully characterized. However, the potential consequences of project delay with the impending onset of winter weather forced this guideline to be superseded in this case. Any materials used in subsequent BCR modules will be fully characterized prior to use.

Conclusions

During bench-scale testing, demonstration-scale design and construction, and demonstration-scale start-up, many lessons were learned. The following list highlights several of the most important conclusions:

1. Bench-scale testing at this site demonstrated that Se, a hard to remove heavy metal, and Tl, a heavy metal about which little is known can be removed in a BCR.
2. Bench-scale testing demonstrated that a BCR cell could effectively remove NO_3^- at acceptable loading rates.
3. Bench-scale testing is an effective tool for determining the optimal sizing, flow rate, substrate mixture, and ‘flushing-maturation’ period for a scale-up to a larger BCR-based PTS. The authors recommend conducting a bench-scale test (on site or in a lab) prior to the construction of any and all larger-scale BCR PTS.
4. A demonstration-scale (pilot-scale) BCR PTS can be constructed in two to four weeks, depending on the size, location, and complexity of the system; the permitting process is often much longer.
5. At least the first three pore volumes of BCR cell effluent should bypass polishing cells to prevent their fouling with elevated levels of BOD and/or fecal coliforms that are present during the ‘flushing-maturation’ stage of a BCR. The first three pore volumes of BCR effluent should either be pumped back to the top of a system (a land application system in the case of this site) or treated prior to discharge.
6. A BCR can remove Tl successfully, even at higher than design loading rates; it can even continue to function during non-routine BCR maintenance activities.
7. A BCR can remove Se at retention times 25% shorter than the design value life at this site, but the Se appears to be subject to re-mobilization if the anaerobic conditions in the substrate are not maintained (e.g. – during the BCR retrofit in the fall of 2008).

8. A demonstration-scale (pilot-scale) BCR PTS can operate through winter in extremely cold environments, such as central Montana, as long as 'winterizing' precautions are taken. Such precautions may include, but are not limited to: burying all piping below maximum frost line for that area, providing extra insulation on and around potential weak spots in the system (vaults, piping, etc.), and establishing flow through the entire system (including polishing cells) prior to the onset of freezing conditions at the site, if possible.
9. A BCR can operate through winter in extreme environments (8+ days of 0° to -35° F weather) without insulation on the surface of the BCR. Based on conditions observed, at least six inches of water should be maintained above the top of the substrate to allow for a layer of ice to form, below which the influent MIW can still flow.
10. It may be difficult to operate full-scale polishing cells throughout the winter, even with optimal start-up conditions and design considerations. For this reason, it is prudent to include a means to bypass some or all of the polishing cells during the coldest periods of the year. Alternative aerobic polishing cell designs are being considered to address this design challenge.

The demonstration-scale BCR PTS will continue to be monitored and sampled over the coming months. During this time, field and analytical samples will be examined and further operational hypotheses will be developed and tested. If the demonstration-scale system operates satisfactorily and meets MTDEQ guidelines, a second BCR cell (with non-As bearing substrate) will be constructed next to the original BCR cell and the system would be expected to treat all of the MIW from the tailings drainage year round without difficulty.

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