BIOCHEMICAL REACTOR SYSTEM AT THE BRULE MINE: A SEMI-PASSIVE APPROACH TO OPERATIONAL AND POST-CLOSURE SELENIUM AND NITRATE REDUCTION

Trudy Miller, E.I.T.[1]
Michelle Marshall, M.Sc., M.B.A., E.P.[1]
Guy Gilron, M.Sc., R.P.Bio., ICD.D[2]

[1]Conuma Coal Resources, Brule Mine, Box 2140,
Tumbler Ridge BC V0C 2W0 Canada

[2]Borealis Environmental Consulting Inc., 148 East 25th Street
North Vancouver BC V7N 1A1 Canada

ABSTRACT

Long-term management of selenium and other parameters, specifically, innovative treatment technologies applied to final effluents, has been established at coal mining operations throughout North America. A holistic approach to site-wide selenium and nitrate management is being developed at Conuma Coal's Brule Mine, in northeastern British Columbia, in the context of the post-closure phase of the mine life cycle. The purpose of this study is to improve upon the application of semi-passive treatment system comprising a biochemical reactor (BCR). Conuma Coal's objective for the system is to reduce selenium, nitrate, and other parameters. The BCR will be used as a tool to aid in the on-going improvement of water quality leading to the goal of compliance with provincial permits and proposed national effluent limits. The basic design and initial construction of the BCR treatment system took place in 2015, with a recent upgrade in 2017. A sampling strategy for effluent monitoring has been established to evaluate the system. Based upon a year of accumulated operating data, parameter concentrations have trended downwards. To date, the BCR has demonstrated success: selenium has been removed in the range 50-90%, while nitrates have been removed in the range 65-99%. Several challenges have been encountered in implementing the system, yielding a number of lessons learned, including: sequencing and flow control are crucial to the proper functioning of the BCR system; sediment curtains help to reduce sediment load to the aerator; and, raised edges help to reduce surface water run-off entering BCR system. Future work relating to the dynamics of resident microbial communities is being planned.

Keywords: coal mining, selenium, nitrate, treatment, effluent, microbial.

INTRODUCTION

The Canadian coal mining industry, comprising both thermal and metallurgical coal mines in four provinces, operates within a rigorous regulatory environment. Mines are potentially subject to up to 35 federal *Acts* and *Regulations*, depending on site-specific conditions. Mines are also subject to many more provincial laws, regulations and mine-specific permits. Moreover, the coal mining sector, similar to the metal mining sector, operates according to stringent reclamation standards; specifically, provinces ensure the sector's legal responsibility for reclaiming land disturbed by mining activities through risk-based security bonding.

Federal. Regulation of coal mines under the federal government commences according to the *Canadian Environmental Assessment Act*, which includes a pre-application phase, notification, development of a Terms of Reference, culminating in an Environment Impact Statement. There are a number of triggers for federal authorizations (*e.g.,* potential impact to fish habitat (*Fisheries Act*), wildlife species protection (*Species at Risk Act*, *Migratory Birds Convention Act*), and impingement on/proximity to federal or First Nations lands, involvement with cross-provincial or international transport (*Navigation Protection Act*). With respect to impacts of coal mine effluent discharges, there are no federal limits currently in place; however, coal mine effluents nevertheless fall under Section 36 of the *Fisheries Act* (*e.g.,* due to failure of trout acute lethality tests). Environment and Climate Change Canada (ECCC) is currently in the process of developing a *Coal Mining Effluent Regulation*, which will likely come into force in 2021. This new regulation will – among other elements - impose effluent limits for pH, total suspended (TSS), selenium, nitrates, and, similar to that being implemented by the pulp and paper and metal and diamond mining sectors, a comprehensive Environmental Effects Monitoring (EEM) program.

Provincial. Provincial governments regulate coal mines according to the province-specific environmental assessment offices/departments, and these include a pre-application phase, notification, development of an Application Information Requirements (BC), culminating in an Environmental Assessment Certificate (BC). Once operating, coal mines are then subject to various provincial permits and approvals, including effluent quality standards, established through approval processes. With respect to impacts of effluent discharges from coal mines, it is generally required that receiving waters downstream of mine sites meet applicable ambient water quality guidelines (*i.e.,* national, (CCME) federal (ECCC), and provincial). British Columbia (BC) guidelines can be modified - on site-specific bases - into "in-stream" water quality objectives to address specific receiving water issues (*e.g.,* high background). Since 2016, development of science-based environmental benchmarks (SBEBs), are developed into Site Performance Objectives (SPO); these are specified in environmental management permits, and are established with associated monitoring frequency and reporting requirements (BCMOE, 2016).

Coal mining effluent characteristics and management

As indicated above, monitoring and reporting of several key parameters in effluent discharge and at compliance points are conducted per provincial permits/approvals/authorizations. This includes acute lethality testing with fish (rainbow trout, *Oncorhynchus mykiss*) and/or invertebrates (*Daphnia magna*). Compliance point (*i.e.,* end-of-pipe or in-stream) limits are generally set for 4 major parameters: total suspended solids (TSS), nitrates, sulphate, and selenium. These parameters are the focus of mitigation measures and water management, including treatment. Conventional means of mitigation (*e.g.,* diversion, settling, and recycle/reuse) are used at many coal mines. Treated effluent discharged into the receiving environments must meet permit requirements. Provinces are responsible for issuing effluent permits in the development of new and expanded coal mines.

Selenium management

Selenium has been identified as a parameter that is consistently elevated in coal mining effluent. The management of selenium requires holistic site-wide mitigation strategies. This usually includes a combination of various techniques, including, but not limited to: diversion of mine-influenced waters (*i.e.,* "keeping clean water clean"), on-site utilization of affected waters (*i.e.,* re-use/re-cycle), and active management of mine-influenced waters (*e.g.,* diversion ditches, sedimentation ponds). When it is determined that permitted effluent limits cannot be met, passive, semi-passive and active treatment systems are often employed.

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Biochemical Reactor Systems: Overview

The general concept behind BCR systems is based on the activity of naturally-occurring bacteria in the biological mixture, this mixture operates to remove oxygen from the water. Once oxygen is removed, microbial communities begin to metabolize selenium, nitrates, and sulphate. It should be noted that the order of removal is not necessarily consistent, as microbial diversify and specialize in the consumption of different parameters. The waste produced by the BCR, consisting of selenium precipitates, nitrous and sulfuric gases, are relatively minor in concentration and are easily managed.

BCR Semi-Passive Treatment System

The purpose of this study is to monitor and improve upon the application of a semi-passive treatment technology comprising a BCR system at Conuma Coal's Brule Mine, in northeastern British Columbia. Conuma Coal's objective for the system is to reduce selenium, nitrate, and other parameters. The BCR will be used as a tool to aid in the on-going improvement of water quality leading to the goal of compliance with provincial permits, proposed federal *Coal Mining Effluent Regulations* national effluent limits, and ambient water quality guidelines downstream of the mine.

The BCR treatment system was initially designed and constructed in 2015. Figures 1 and 2 below illustrate the general design and concept, in relation to the mine operation. Seep water from Brule's North Dump enters the Main Sediment Pond (MSP) along with surface contact water. The BCR influent is water pumped from the discharge end of the MSP to the BCR. Treated water leaves the BCR through an Agri-Drain and enters the aeration pond where it is aerated prior to discharge back into the MSP. Discharge from the MSP flows into Blind Creek where it reaches the BC-01a compliance point.

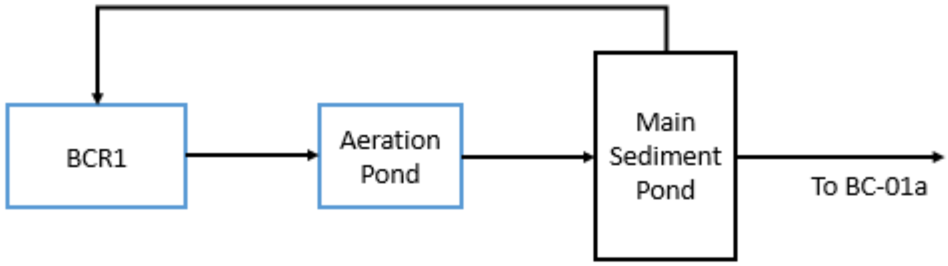

Figure 1. Biochemical Reactor System at the Brule Mine: Design concept. BCR1 = biochemical reactor; BC-01a = in-stream location for monitoring site performance objectives (SPOs).

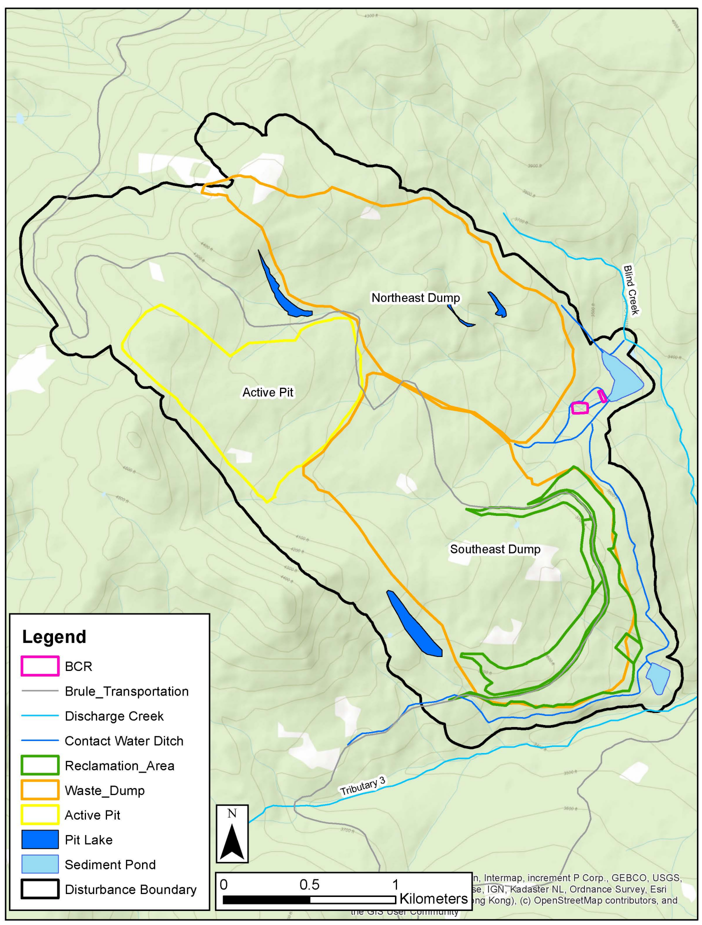

Figure 2. Overview of Brule Mine, illustrating the location of BCR System.

The following photos (1-3) represent the 2017 reconstruction of the inner workings of the BCR.

Photo 1. Reconstruction of BCR treatment cell, geosynthetic liner placement. 2017.

Photo 2. Reconstruction of BCR treatment cell, establishment of overlying substrate layer. 2017.

Photo 3. Reconstruction of the BCR treatment cell, with full substrate layer. 2017.

Effluent Monitoring to Evaluate Removal due to Treatment

In order to evaluate the removal of key parameters by the BCR treatment system, a sampling strategy was developed. this strategy included the location and frequency of sampling stations for influent and effluent monitoring. Figure 3 below illustrates the sampling locations, in the context of the BCR, and the Aeration (which functions to re-aerate the water) and Main Sediment Ponds.

The sampling locations (illustrated in Figure 3) are as follows:

- BCR-IN – upstream of BCR system;
- AgriDrain – effluent from BCR system, prior to Aeration Pond;
- BCR-D – downstream of Aeration Pond; and,
- MSP-D – downstream of Main Sediment Pond.

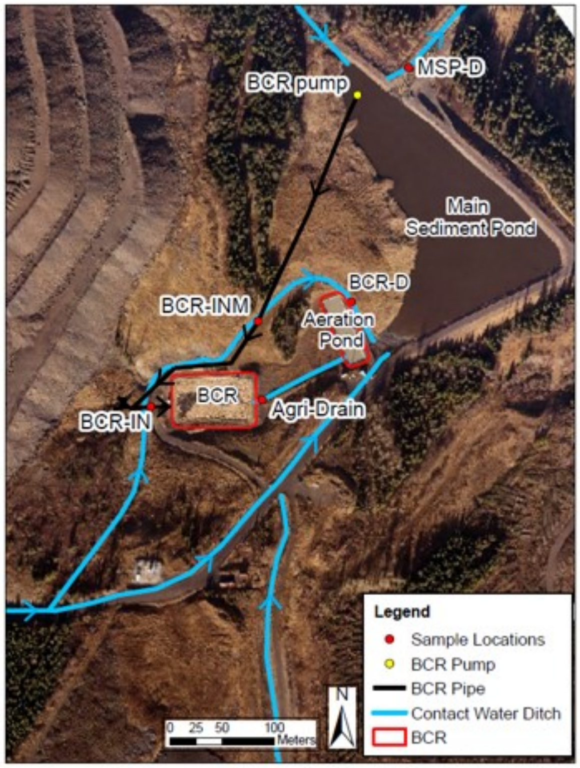

Figure 3. Sampling Locations for Monitoring the Efficacy of the BCR System at the Brule Mine.

RESULTS

The trends in parameter concentrations have been monitored since July of 2018 (a period of one year), and have demonstrated a consistent reduction in both selenium and nitrate over time. A summary of the results for two major parameters of concern is as follows:

- selenium (Se) removal from effluent (*i.e.,* difference between [Se] at BCR-IN and AgriDrain) in the range 50-90% (Figure 4 (total selenium concentrations over time)); and,
- nitrate (NO_3) removal from effluent (*i.e.,* difference between [NO_3] at BCR-IN and AgriDrain) in the range 65-99% (Figure 5 (total nitrate concentrations over time)).

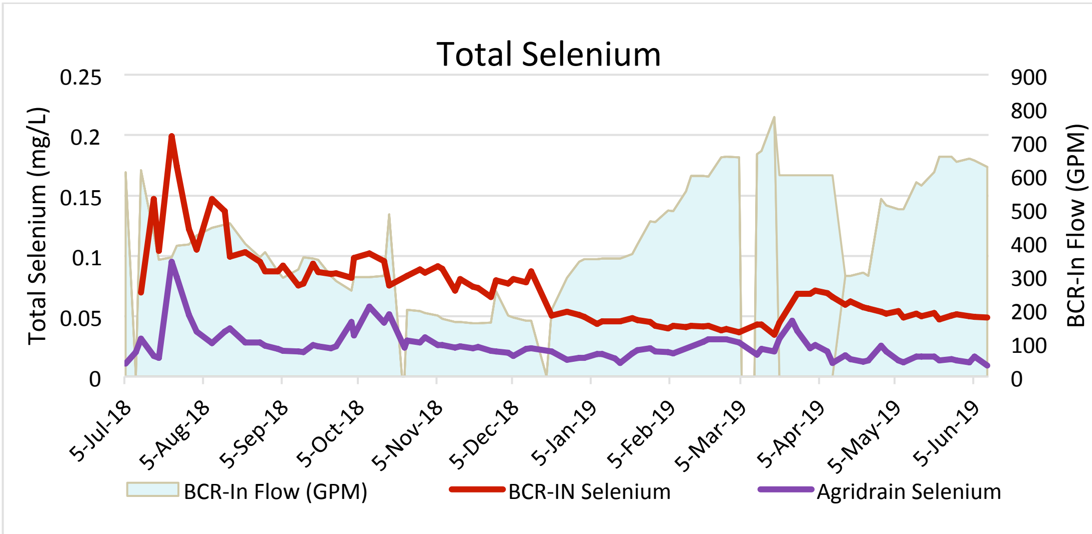

Figure 4. Selenium concentrations over time at BCR System monitoring locations, Brule Mine (Conuma Coal).

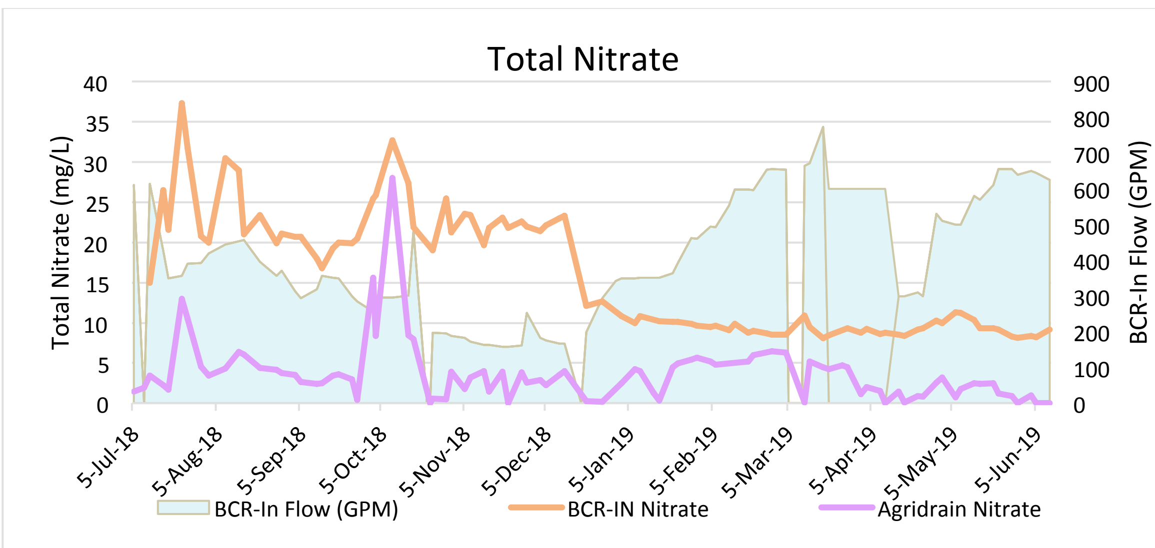

Figure 5. Nitrate concentrations over time at BCR System monitoring locations, Brule Mine (Conuma Coal).

LESSONS LEARNED

A number of challenges have been encountered during the implementation phases of the BCR System. The first of these relates to the maintenance of constant effluent flow into the BCR, this is crucial to the operation of the BCR (Golder, 2009; Hatch, 2014). Moreover, in-flow concentrations of major parameters (*i.e.,* selenium and nitrate) can vary significantly; this can also impact removal success. In addition, sediment build up can compromise the operation of the system; proper sediment removal prior to water entering the BCR will mitigate this issue. Finally, maintaining microbial activity within the BCR is also a key factor; however, understanding microbial dynamics will help to overcome this (see Future Work, below) (Hatch, 2014; USEPA, 2014).

In response to the above, the following improvements have been made, including:

1. in-flow water now by-passes the BCR system and reports to the Main Sediment Pond (MSP);
2. sediment into the BCR system has been reduced;
3. a new heat-traced line installed from MSP to feed BCR at constant rate; and,
4. there is a current evaluation of placing a sediment curtain in the Aeration Pond to allow the microbes time to settle/acclimate.

The following are the lessons learned to date:

- sequencing and flow control are crucial to the proper functioning of the BCR system;
- sediment curtains help to reduce sediment load to the aerator; and,
- raised edges help to reduce surface water run-off entering BCR system.

FUTURE WORK

Future work, aimed at understanding the mechanisms responsible for the operation of the system, and potential enhancements, is on-going. The next focus of system improvement is evaluation of the resident microbial communities within the BCR system. The communities will be assayed to: enumerate cell numbers; evaluate and screen bacterial metabolism; profile community-level physiology, and, fingerprint bacterial DNA.

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