Field Scale Prototype Anaerobic/Wetlands Cells For Removing Heavy Metals from Water

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Abstract – *A passive treatment system utilizing an anaerobic digester followed by three plant based treatment cells has been built in Trail, British Columbia, site of the world's largest non-ferrous smelter. Water becomes contaminated with heavy metals as it passes through discarded materials from the smelter and through a former Arsenic dump. This water, containing large amounts of dissolved Zn, Cd, and As is collected and pumped to the pilot scale treatment facility.*

The facility, capable of treating 12-15,000 liters of water each day includes a large anaerobic digester that utilizes waste by-product from the pulp and paper industry as a matrix for Sulphur Reducing Bacteria. The partially treated water then flows through a series of hydroponics cells containing a mixture of metal-resistant fast growing plants. The system uses gravity based hydroponics flow-through and solar powered aeration cells between garden cells.

During the summer months transpiration will yield expected (or greater) results. All plants are perennials and after two months of operation there were no signs of impaired plant functioning. The system has been designed to operate year round although during winter months treatment levels will be lower.

Site Problem

A capped landfill, formerly used as a dump for discarded materials and equipment from the COMINCO smelter in Trail BC, produces a leachate that contains heavy metals. Water percolating through the landfill dissolved metals and moved downwards through an extensive layer of sand until bedrock was reached. At this point it moved laterally, eventually making its way to a creek and into the Columbia River. COMINCO hired an engineering firm to characterize the water flow and they subsequently designed and built a collection system that funneled the water into a sump. From there it is pumped to a traditional Effluent Treatment Plant but could be sent to any other treatment system.

Table 1: Total volume of water and some of the heavy metal contaminants entering Stoney Creek daily from seeps originating from capped landfill and from Arsenic dump. Volumes from separate seeps have been combined and amounts calculated to reflect metal contaminant based on percentage of total volume.

Total Volume/Day	Containing Following Heavy Metals (ppm)			
	Arsenic	Cadmium	Zinc	Lead
77,000 liters	45	3.64	205	0.056

Northern Water, Environment & Training Services was contracted by Bill Duncan, Biologist, Trail Operations at COMINCO, to design and build a prototype phytoremediation treatment system.

System Design and Construction:

During the summer of 1997 a series of self-contained sub-surface flow wetland cells were constructed on a COMINCO owned property. The property was ideal topographically and, in addition, had a stream of clean water that ran year round. A local contractor was hired to build three treatment cells and two aeration cells. The cells were designed and built using typical constructed wetland techniques (Kadlec, Knight, 1996).

Cells were planted with fast growing plants and kept watered using the clean water from the local stream for the first year while root growth was established. The first cell is 50m^2 and includes grasses, selected shrubs and perennials and several species of hybrid poplar and willow. The second cell, also 50m^2, contains several species of grasses some of which are indigenous to the immediate area. The third treatment cell, 300 m^2 is planted with *Typha latifolia*.

Oxygen depletion during treatment in each cell was an important system design. Accordingly, a 6m^{2}aeration cell was built between cells one and two and two and three. These cells serve as the location for a control system to set water level in the preceding cell and they are convenient sample points for testing purposes.

A final large lined holding pond was built as the final stage in the system. Water is held there for final testing before being delivered back to the environment.

The system was built during the summer of 1997, planted with seedlings of the species being considered for permanent use and allowed to grow over the course of the summer without the addition of contaminated water.

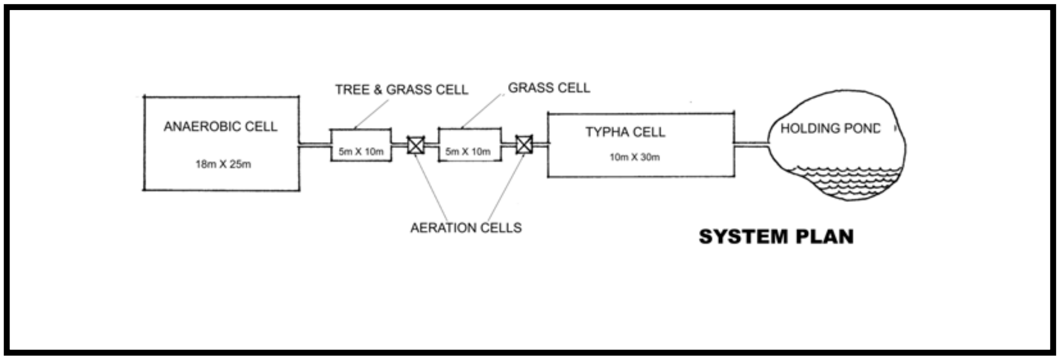

Figure 1: Plan of prototype system as installed in Trail British Columbia for removal of heavy metals from landfill leachate. Water enters system at left of Anaerobic cell and flows downhill through each cell to holding pond. Collection points are at the exit from each cell.

Bench-scale Testing

With the co-operation of Dr. W. Rauser and Dr. B Husband at the University of Guelph, space was secured in the greenhouse for bench scale testing. Models of the system as built in Trail were constructed and planted with the species being investigated. Large containers, each containing one or more of the metals found as contaminants in the leachate were used to provide water at a rate that corresponded to that planned for the field-scale system. Four systems were built using solutions representing 5, 10 and 40% of the metals present in the leachate as well as a control.

This greenhouse research showed that metal levels in unadulterated leachate were too high for the chosen plants and that levels would need to be reduced by 50 - 90% if treatment were to be successful. Both dilution and pre-treatment using an aerobic digester were considered before deciding on the second option.

During the same period work at COMINCO Research was carried out examining the efficacy of various biomass materials to remove metals in an anaerobic environment. This work showed that as much as 90% of the metals present in the leachate could be removed using a locally available waste biomass product easily available from a pulp mill.

Taken together these results lead to a decision to construct a large anaerobic digester rather than solve the concentration problem by dilution.

Therefore, during the early summer of 1998 a large anaerobic digester, based on the research carried out at COMINCO research facilities was built.

Design of Anaerobic Cell:

Sizing:

Correct and sufficient size of this cell is important. Both volume of water to be treated and concentration of dissolved metals are parameters that must be considered.

Volume:

The potential to treat 20,00 liters per day (13.9 L/min) was used to estimate cell area. The volume sized 'rule of thumb' used in calculation based on metal concentrations is the removal of 0.3 mol/(m^3d) of metal where the volume component is the total volume neglecting the pore space and moisture content (Dvorak et al, 1991; Hedin et al, 1989; Gusek and Wildeman, 1997). Zinc content can range up to 500 mg/L and Cd. up to 10 mg/L and As up to 45 mg/L. Therefore: Cell Volume = (155 mol/d)/(0.3 mol/(m^3d) and Cell Volume = 517 m^3

Area:

The area based 'rule of thumb is estimated to be between 10 m^2min/L and 20 m^2min/L (Gusek and Wildeman, 1997). This factor is pH dependent upon pH in the range of 5-7 with higher pH values requiring lower loading factors. Cell Area = (20m^2min/L) X (13.9 L/min) and Cell Area = 278 m^2

Biomass Composition

Composition of biomass used: Celgar residuals 60%, Sand 35%, Cow Manure 5%.

Based on these parameters and allowing for adjustments due to site characteristics a cell was constructed that was 24 m X 18 m at the top with sides that sloped to a bottom area that was 18 m X 10 m. The total depth was 3.5 meters.

Results:

Late in the growing season the construction work had been completed and all necessary pipelines laid. Metal contaminated water was pumped into the anaerobic and following cells and allowed to remain for several days. This allowed for a period of stability and a first flush of the dissolved organic material. . After a few days samples were taken. Samples were gathered using a grab sample method from:

- A valve stem installed at the top of the vertical header that delivers water to the bottom of the anaerobic cell. This provided the raw sample of contaminated water.
- From the outflow of this cell as it enters a specially constructed small aeration device,
- At the outlet of each of the three subsequent plant based treatment cells.

An initial set of samples was taken August 9th, followed by further samples in late August, late September and early October. In total, four sets of samples were taken and assayed using ICP/AES for the three metals of interest, Zn, Cd, and As.

Table 2: Zinc, Cadmium & Arsenic (mg/l) in each stage of a four-stage biologically based treatment system. Percent removed represents the percentage of dissolved metal entering the cell that was removed during passage through that cell.

Date	Stage	Zinc	% removed	Cadmium	% removed	Arsenic	% removed
09/8/98	**1st input**	**130**		**3.6**		**45**	
	output to trees	78	40.00	0.43	88.00	8.1	82.00
	output to grass	7.9	89.90	0.3	30.23	1.5	81.48
	output to *Typha*	4.3	45.57	0.18	40.00	0.62	58.66
	output to pond	0.12	97.21	0.01	94.40	0.05	91.90
% removed from all stages			**99.90**		**99.70**		**99.89**
24/8/98	**1st input**	**205**		**3.4**		**42.0**	
	output to trees	78	61.95	0.45	86.76	9.5	77.38
	output to grass	31	60.26	0.36	20.00	5.0	47.37
	output to *Typha*	24	22.58	0.29	19.44	3.4	32.00
	output to pond	3.9	59.11	0.1	65.52	0.79	76.76
% removed from all stages			**98.09**		**97.06**		**98.12**
22/09/98	**1st input**	**140**		**2.3**		**23**	
	output to trees	88	37.14	0.16	93.04	8.2	64.35
	output to grass	74	15.90	0.14	12.5	8.4	(+2.3)
	output to *Typha*	1.9	97.43	0.04	71.42	1.5	82.14
	output to pond	0.38	80.00	0.02	50.00	0.48	68.00
% removed from all stages			**99.72**		**99.1**		**97.91**
02/10/98	**1st input**	**75**		**1.0**		**17**	
	output to trees	72	4.00	0.21	79.00	8.0	52.94
	output to grass	50	30.55	0.11	47.62	5.8	27.50
	output to *Typha*	0.56	98.88	0.02	81.82	0.82	85.86
	output to pond	0.54	3.57	0.01	50.00	0.56	31.70
% removed from all stages			**99.28**		**99.00**		**96.71**

The system was designed to treat 10-15,000 liters a day during the summer months when plants are growing most rapidly and using water and nutrients. Unfortunately contaminated water was not introduced until relatively late in the growing season giving less that a full season's results.

Metal Speciation

The system design included a layer of non-woven geotextile laid down over the biosolids mixture and a layer of sand on top of that, however, a certain amount of metal sulphides were expected to move through this filtering mechanism into the plant containing cells. A filtering mechanism had been included at the outlet of each of the cells before water exited to the aeration units. The system had been designed with an understanding that anaerobic activity would take place in all of the cells. As a result of this activity we anticipated that additional metal sulphides would be formed. This did, indeed occur and the results are evident when examining the continuous reduction of metals in the water as it flows through each stage of the system. However, since samples were taken from aeration cells and from the exit of the anaerobic cell some metal sulphides were included in each sample. Therefore, some of the metals measured present in the cells could be metal sulphides as assays did not differentiate between dissolved and insoluble metals present.

Volume Treated

Setting flow rates was a trial and error procedure. Since the metal-containing water was being introduced for the first time the system was initially kept at less than 50% potential treatment volume. This ensured that a steady state anaerobic condition was attained in all cells and that plants would not be flooded with concentrations of metals that were not sustainable to life.

Table 3: Volume treated (L/d) measured as output of the anaerobic cell

Date	Volume leaving anaerobic cell
12/09/98	10,944
13/09/98	12,470
14/09/98	13,252
15/09/98	17,855
16/09/98	13,828
17/09/98	13,603
18/09/98	13,358
19/09/98	14,842
20/09/98	13,714
21/09/98	6,768
22/09/98 *	13,896
23/09/98	14,592
24/09/98	14,784
25/09/98	8,304
26/09/98	8,640
27/09/98	8,640
28/09/98	12,144
29/09/98	12,638
30/09/98	13,171
Average (19 days)	**12,497**

* Note that there were samples taken for assay during the time frame described in this chart as well as one immediately following this time period on October 2nd.

The average flow through during this period is what is expected during operations throughout the summer months. Flow through was markedly lower on four days when levels in the anaerobic cell had dropped below the threshold required to maintain adequate flow. The anaerobic cell is charged over a 1-2 day period then runs about 1 week into the other cells.

Following this period the system was once again slowed down as plants were well advanced into senescence and transpiration had stopped or severely slowed down.

Future Considerations:

We are encouraged by the results obtained to date and are looking forward to a full growing season of operations. We expect to begin operations this spring as soon as snow cover has gone, plants have begun to emerge and leaf buds have broken. Additional tree material will be planted and the system checked against over-wintering damage. Solar powered aeration units will be re-installed and augmented as required.

A complete season's operations will provide greater understanding of the systems potential and, at the same time, ensure a detailed record of operation values throughout spring, summer and fall.

Now that the system is fully planted and plants have reached a mature level of root growth, additional procedures will be implemented that will ensure a more detailed testing of many facets of the system's operating parameters.

This season we will:

- Plant a tree cover on landfill and install measuring equipment to monitor changes in water flow through
- Investigate metal speciation in the anaerobic cell with particular reference to arsenic;
- Research passive filters to remove metal sulphides from suspension;
- Assess each plant species ability to sequester metals;
- Install flow meters at inlets and outlets of the three tiered wetlands system to monitor treatment rates more thoroughly;
- Determine the most efficient residence time in the anaerobic digester while still ensuring adequate flow rates.

An important aspect of the work this summer will be to begin to understand the life expectancy of the system. Core samples of the biological residue in the anaerobic cell will be taken and analyzed to determine levels of metal sulphide build-up and amounts of carbon and sulphur remaining.

Further work will be completed towards the ideal of establishing winter treatment rates as well.

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