Phytoremediation as an *In-Situ* Technique for the Restoration of Oil-Contaminated Sites*

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Phytoremediation is the use of plants and their associated microorganisms for the *in situ* (or on-site) treatment of contaminated soils. Based on a review of relevant literature, we have concluded that phytoremediation is a steadily emerging technology with the potential to facilitate the cleanup of petroleum hydrocarbons at oil-contaminated sites. Initial indications are that phytoremediation is effective at degrading and containing petroleum hydrocarbons in soil as well as transferring these compounds from soil to the atmosphere (Cunningham *et al.*, 1996; Siciliano and Germida, 1998; Sims and Overcash, 1983). The literature suggests that the degradation of petroleum hydrocarbons by microorganisms in the rhizosphere of plants is the primary loss mechanism for these compounds (Gunther *et al.*, 1996; Jordahl *et al.*, 1997; Radwan *et al.*,1998).

Successful trials have involved a variety of plants, but the majority of research has focused on grass and legume species (Aprill and Sims, 1990; Qiu *et al.*, 1997; Gunther *et al.*, 1996; and Reilley *et al.*, 1996). In fact, a number of legumes have been found to grow naturally in oil-contaminated areas (Gudin and Syratt, 1975). Our preliminary screenings indicate that several plants native to the Prairie and Boreal Plain Ecozones of Western Canada, as well as several introduced species, may be useful in phytoremediation efforts within these areas.

The effectiveness of phytoremediation is site-specific in that it can be greatly affected by environmental conditions. Phytoremediation is facilitated by adequate quantities of nutrients, water and oxygen and is enhanced at warmer temperatures (Wright *et al.*, 1997). Phytoremediation potential may be restricted in soils with abundant organic matter or clay – soil components that tend to reduce the bioavailability of petroleum hydrocarbons (Otten *et al.*, 1997; Cunningham *et al.*, 1996). It may also be inhibited if contaminant concentrations are too high or too low (Committee on *In Situ* Bioremediation *et al.*, 1993; Hrudey and Pollard, 1993; Rogers *et al.*, 1996; Atlas and Bartha, 1998).

Certain petroleum hydrocarbons are easier to phytoremediate than others. In general, BTEX compounds are relatively easy to remediate because they are (i) rapidly degraded in the presence of oxygen; (ii) relatively soluble, thus making them bioavailable; and (iii) can serve as the primary electron donor for many bacteria widely distributed in nature (Committee on *In Situ* Bioremediation *et al.*, 1993). Large and lipophilic compounds such as the four and five-ring PAHs are more difficult, though not impossible, to remediate. The remediation of these compounds is more difficult because of their limited

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bioavailability, which is a result of their adsorption to soil organic matter and clay, as well as their limited ability to pass through cellular membranes of plants and microbes (Cookson, 1995). Nevertheless, cometabolism by microorganisms has been shown to result in the degradation of some large PAHs, such as benzo[*a*]pyrene (Kanaly *et al.*, 1997). In general, weathering processes selectively reduce the concentration of easily-degradable contaminants, making older sites more difficult to phytoremediate than newer sites (Bossert and Bartha, 1984; Cunningham *et al.*, 1996).

The three major alternatives to phytoremediation are natural attenuation, engineering, and bioremediation. Limited information suggests that phytoremediation is slightly less expensive than bioremediation and can be orders of magnitude less expensive than some of the more costly engineering techniques (Cunningham *et al.*, 1996; Cunningham *et al.*, 1995, Tsao, 1999; Bollag *et al.*, 1994). It is faster than natural attenuation, but typically slower than engineering and bioremediation. Because phytoremediation is an *in situ* technique, it is less disruptive compared to the excavation efforts required in *ex situ* engineering and bioremediation. Phytoremediation is most likely to have the greatest effectiveness with shallow contamination, which is co-incidental with the greatest root density. A variety of remediation approaches may be required to accomplish all reclamation goals at a contaminated site (Hrudey and Pollard, 1993). The type of approach or approaches chosen will most likely be site-specific and depend on the desired speed of reclamation as well as the number of dollars dedicated to the reclamation effort.

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1996). There is a single large toroidal vortex created, i.e. like a donut shaped tornado, which is driven by a surface layer traveling radially outward from the pond mill. The surface velocity remains quite high even at large distances from the pond mill. The reason for this phenomenon is that upwelling is present over most of the pond, e.g. between the pond mill and the vortex center located close to shore (J. D. Bugg, 1996). The oxygen transfer rate of the Little River Pond Mill® was found to be 1.47 g O_2/W h with an average wind speed of 5.33 m s^{-1} which is comparable with the oxygen transfer rate of other low speed surface aerators (C. Ruiu et al. 1997). It should be noted that the results of this test are skewed to the negative due to the deoxygenation chemical used. The chemical used has a higher efficiency rating under circulating conditions which was not taken into consideration when the quantity of chemical was added. We are presently setting up an experiment using nitrogen gas as the deoxygenation agent since it does not have a residual effect under circulating conditions.

4.0 Research Results

4.1 Flow

4.1.1 In a 4 m x 15 m pond, with a 6.71 m s^{-1} wind, a single, large, toroidal vortex of 9 m^3 s^{-1} is created. (J. D. Bugg, 1996)

4.2 Oxygen Transfer Rate

4.2.1 OTR = 1.47 g O_2/W h with an average wind speed of 5.33 m s^{-1}. This is comparable with the oxygen transfer rates of other low speed surface aerators. (C. Ruiu et. al., 1998)

4.3 Biological Oxygen Demand

4.3.1 Reduction of effluent vs. influent - Omemee Sewage Lagoon, Omemee, ON, 1991

% Reduction	Influent	Effluent
89.8 - 99.8 %	167 mg/L	1.1 mg/L

4.3.2 August 1998, Municipality of Val Barrette, QB: < 5.0 mg/L; maximum allowable limit is 25 mg/L summer, and 30 mg/L winter. Initial values were not provided therefore a comparison cannot be made; information provided can only be used as an indicator Eco-Guide Environnement, Lachute, QB

4.4 Dissolved Oxygen

4.4.1 Pond mills installed on sewage lagoons, Village of Milligan , Nebraska, USA, May 25, 1995

Date	Dissolved Oxygen
25-05-95	2.3 ppm @ 3 feet
29-07-95	8.9 ppm @ 3 feet

4.4.2 Pond mills installed on Pointe Calumet Lake, QB, June 06, 1997 - Super Aqua Club

Average values of Pointe Calumet Lake on June 06, 1997

	Depth (meters)						
	0	1	2	3	3.5	4	4.3
Temp (° C)	21	21	20	17.5	16	16	15
0_2 (mg/l)	11	11.2	11.2	10.5	10.3	10.2	2.6

Site 1 and 2 combined - Pointe Calumet Lake average values on August 07, 1997

	Depth (meters)						
	0	1	2	3	3.5	4	4.3
Temp (° C)	23	23	2.75	22.5	22.5	22.25	22.25
0_2 (mg/l)	9.3	9.3	9.3	9.3	9.8	8.4	7.7

A mixing of the lake has altered the supersaturation oxygen values at the surface and facultative to anaerobic conditions near the bottom, observed on June 06, 1998, and created an even temperature and oxygen profile throughout. This enables indigenous organisms to compete more efficiently thereby increasing the natural diversity of the lake.
Eco-Guide Environnement, Lachute, QB, 1997

4.5 Microbial Action

4.5.1 Fecal coliform reduction of Pointe Calumet Lake, QB (recreational urban lake with water slide). Prior to pond mill installation: 300 cfu/100 ml, after pond mill installation: < 2 cfu/100 ml
Eco-Guide Environnement, Lachute, QB, 1997-98

4.6 Ammonia (NH_3)

4.6.1 Major hog processor in USA; processes 16,000 head of hogs with 2 million gallons of waste water, daily; 18 pond mills installed on intermediate, 30 surface acre (5 foot depth), aerated lagoon (which had the required number of 200 hp aerators in operation). It was found that the aerators (located on a 4 surface acre leg of the primary lagoon) were not operating efficiently and maintenance was extremely expensive. The finishing lagoon, 30 acres with a 3 foot depth, had 6 mills installed.

Intermediate lagoon

18-05-95 (prior to installation)	24-07-95 (60 days after installation)
110-120 ppm	55-60 ppm

Excel Corporation, 1996

4.7 Suspended Solids

4.7.1 Reduction of effluent vs. influent - Omemee Sewage Lagoon, Omemee, ON 1991

% Reduction	Influent	Effluent
89.2 - 99.8 %	240 mg/L	0.5 mg/L

4.8 Odor Potential (ou/L)

4.8.1 control = 226,237 ou/L; test = 97,819 ou/L

ou = odor units
(Michael R. Toombs, 1997)

4.9 Total Phenols
4.9.1 control = 3.06 mg/L; test = 0.25 mg/L
(Michael R. Toombs, 1997)

4.10 Total Volatile Fatty Acids (VFA's)
4.10.1 control = 6904 mg/L; test = 113 mg/L
VFA's below 230 mg/L correspond to a liquid manure without offensive odors
(Michael R. Toombs, 1997)

5.0 Conclusions

The circulation action, combined with the passive and active aeration promoted by the pond mill, favors a more complete decomposition of organic matter, mineralization of nutrients, and an overall change in the population dynamics of the body of water thereby creating an environment which is more diverse and verging on equilibrium. Within this system the byproducts of respiration of one organism are utilized by another organism, on down the line, ensuring a complete nutrient and carbon cycling and very efficient, and inexpensive, remediation process.

The benefits of the bioremediation can be seen in such parameters as:
1) reduction of odors and toxic respiration byproducts by moving away from the anaerobic processes which produce those substances. By reducing or eliminating toxic gases, reductions in mid or late winter fish kills are possible, as well as increases in vertebrate, non-vertebrate, and microbial diversity. Recreational use of lakes could also become more pleasant.
2) reduction in factors such as BOD, SS, phenols, VFA's, and increases in DO and organism populations diversity of the water can improve both the image and the functionality of the body of water.

The environmentally friendly remediation of surface water supplies, waste water, and liquid sewage, through use of Little River Pond Mill®, a bioremediation facilitator, provides environmental, economic, and social benefits to the environment, the commercial animal producer, and the surrounding community. It can reduce environmental, economic, and social costs associated with surface water, waste water, and liquid manure management.

6.0 References

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