Bioremediation: Case Studies in Central Alberta

Authors:
Alfredo Carcamo M.Sc. P.Ag. and Jeff Powers, M.Sc. P.Geol.

ARC Inc. Environmental Geoscience Engineering and Management. 7535 Flint Road SE Calgary AB T2H 1G3
Telephone: (403) 444 4922 or (403) 543 1945
www.arcinc.ab.ca

Abstract

Hydrocarbon spills that can occur during oil and gas operations may result in a loss of soil quality. This may reduce transport of water and air, inhibit microbial activity, and nutrient cycling. Remediation of hydrocarbon impacted soils can take place in-situ and/or ex-situ through physical and biological treatment processes. Successful treatment requires an understanding of physical, and biochemical properties of pollutants as well as impacted soils. Careful selection of treatment processes can reduce site disturbance, volume of soil to be treated, thereby reducing remediation program costs.

This paper focuses on case studies of remediation programs conducted in central Alberta using biological treatment techniques. Generally, the projects developed from phase II environmental site assessments conducted on active oil and gas sites. Hydrocarbon impacted soils were sampled and analyzed for salts, metals and petroleum hydrocarbons to evaluate remediation options. Soils reported with impacts from salts and metals were excavated and hauled off-site for disposal. Soils impacted with petroleum hydrocarbons in the (C5 to C30) fraction were selected for on site treatment. Previous experience has shown that this fraction can be degraded through a combination of physical and biological processes.

Soils impacted with petroleum hydrocarbons were excavated and stored on site while an on site treatment pad was constructed. Treatment consisted of nutrient amendment as well as aeration using a trackhoe equipped with a mixing head. Soil samples were collected and analyzed over time to evaluate the soil quality, when analytical results reported contaminant levels were below selected criteria, soil treatment was complete. On site remediation processes resulted in significant reduction costs primarily owing to decreased transportation and land fill charges.

Introduction.

Hydrocarbon impacted soil is encountered in upstream and downstream oil production systems throughout many parts of the world. Oil can find its way to soil and groundwater due to spills, leaks, breaks and naturally occuring seeps. Hydrocarbon based constituents released to the environment can reduce soil quality by creating water repellent soils and prevent movement of air in soils, leading to unproductive or less productive land. In the early years of the oil industry, spilled oil was treated by burning it off the land. However, only the lighter oil would burn, leaving behind the heavier fraction which typically formed a thick layer. Environmental managers now have many options to choose from when dealing with hydrocarbon based releases to the environment.

Remediation of contaminated soil and water can be completed in situ, ex situ using engineered systems, or allow nature to do its work by monitored natural attenuation (MNA). The choice of remediation plan will depend on many factors including site location, potential impacts to the site as well as time for remediation. The objective of this paper is to present case studies of bioremediation programs implemented at active oilfield sites in Central Alberta. These are examples of alternative remediation techniques that can be used on active sites for one-time application of oilfield wastes.

Bioremediation

The use of organisms to treat hydrocarbon impacted soils has become well established in the last twenty years through out North America. Microorganisms have long before been used as inoculants in soil, plants, foodstuff and detritus (E.A. Paul, 1996). Microorganisms have been considered "the earth's garbage control agent", and humans have often turned to the land to sanitize their wastes. Composting systems have been used to treat agricultural wastes and municipal solid waste as well as a variety of other organic streams. Experience gained in these areas led to the development of bioremediation technologies for the treatment of organic compounds such as those found in the oilfield wastes.

Bioremediation is the application of organisms with degradative capacities favorable to environmental clean up (Alexander, 1994). Microorganisms with the ability to metabolize hydrocarbon compounds are introduced into the impacted soils and biodegradation of contaminants take place. Biodegradation can involve oxidation/ reduction reactions, partial degradation of the core structure or mineralization. Mineralization refers to the degradation of the original molecule to produce CO_2, inorganics (nitrogen, phosphorus, sulfur), microbial biomass and energy. Mineralization of petroleum hydrocarbons occurs in the same manner as mineralization of native organic matter.

Bioremediation is a process that relies on microbiology and engineering. Understanding the principles that control microbiology of a soil system is as important as being able to design a system that will ensure the parameters can be regulated. Engineering systems range from the simple land treatment to the highly engineered enclosed systems that control volatilized products, leachates and run-off. Bioreactors can be brought on site to treat large quantities of wastes while minimizing site disturbance. The systems that will be highligted in this paper include land treatment and biocells or biopiles. In all cases, hydrocarbon impacted soils were treated on-site and final disposition was on site.

Success of bioremediation programs requires careful planning and a clear understanding of the waste stream, microbial population, nutrient status of soil, and physico-chemical characteristics of soil. Bioremediation programs rely on site specific information that must be evaluated prior to implementation of field scale programs. Soil texture and pH play a significant role in determining the microbial community as well as the quantities of hydrocarbon degraders that will be found at a particular site. In addition, chemical characterization of the hydrocarbons is important relative to the microbial population and its ability to biodegrade.

Bioremediation programs are implemented following an intrusive environmental site assessment. Results of the investigation are used to determine the remediation options. At the time of assessment, an area is selected as a potential location of an on-site treatment cell.

Impacted Sediment Characterization

At the time of asssessment, impacted soils are analyzed for salts, metals and persistent recalcitrant compounds, as well as hydrocarbon characterization and concentration. Soils suitable for on-site bioremediation are selected on the basis of concentration level and nature of contaminants. Light end hydrocarbons such as benzene, toluene, xylenes and aliphatic carbons with chains lengths less than C30 are considered biodegradable. Polyaromatic hydrocarbon based compounds and heavy end hydrocarbons are considered relatively recalcitrant and the presence of high concentrations of such compounds may be unsuitable for biodegradation. Large proportions of heavy end hydrocarbons would reduce the degradation rate and may not be practical.

When heavier end hydrocarbons or polyaromatic hydrocarbons are encountered, the remediation may require a longer time or may reach an asymptote above criteria. Depending on concentration and compound properties, a feasibility study may be conducted to determine whether on-site treatment is the preferred option.

The physical characterization of samples is conducted by determining the texture, color, moisture, density per methodologies recommended by Unified Soil Classification System (USCS, 1960). By determining the physical characteristics of the soil, potential modes for migration, degradation, biodegradation and volatilization of substances in the soil can be inferred. The classification also provides information on natural background conditions in the area.

Field screening and laboratory analytical results are used to identify and assess the degree and extent of possible soil impacts. Volatile vapor headspace readings are collected by half filling a plastic bag with sample media, sealing the bag, allowing vapors to accumulate in the bag for approximately ten minutes. Samples that report elevated volatile hydrocarbon levels are submitted to the lab for analyses.

In the remediation planning case studies presented below, impacted soils that were not suitable for on-site treatment were segregated and hauled to a secure class II landfill.

Material that was treated on site was chosen on the basis of the criteria indicated by Alberta Energy and Utility Board Guide 58: Oilfield Waste Management Requirements for the Upstream Petroleum Industry (AEUB, 1996) and associated Interim Directives as well as Alberta Environment Code of Practice for the Land Treatment and Disposal of Soil Containing Hydrocarbons (AENV, 2001).

Case Study 1 Land Treatment Using a Bulldozer Equipped with a Cultivator.

Land treatment of impacted soils at this site was completed with a bulldozer equipped with a cultivator. The environmental site assessment was completed in 1999, with remediation activities conducted from June to October 2000. Land treatment was initiated in the fall 2000 and lasted for approximately 18 months. At the time of project initiation, Alberta Environment used total petroleum hydrocarbon (TPH) criterion therefore the data for initial assessment is based on TPH criterion. In June 2001, AENV introduced a new set of criteria, Alberta Soil and Water Quality Guidelines for Hydrocarbons at Upstream Oil and Gas Facilities. Thus, the confirmatory sampling was compared to criteria based on petroleum hydrocarbons (PHC) fractions F1-F4 (AENV, 2001).

Construction of a treatment cell involved stripping and segregating topsoil and subsoil for eventual reclamation. Berms and the base of the treatment pad were constructed by compacting existing clay till. Generally a slight gradient was built to allow surface run off. The site occupied by the land treatment area measured approximately 80 m by 90 m. To accomodate on-site facilities, the pad was narrower at the east end.

Soils treated at this facility originated from a former flare pit which was excavated as part of a site remediation plan. Approximately 2,500 m^3 were treated in the southern half of the treatment cell, and another 500 m^3 were treated in the northern half of the treatment pad. Benzene, ethylbenzene, xylenes and total petroleum hydrocarbons (TPH) were reported above Alberta Tier I Criteria (AENV, 1994). Up to 6100 mg/ kg TPH were reported in the impacted soil.

TABLE 1: Initial Sample Concentrations for Case Study 1 Land Treatment

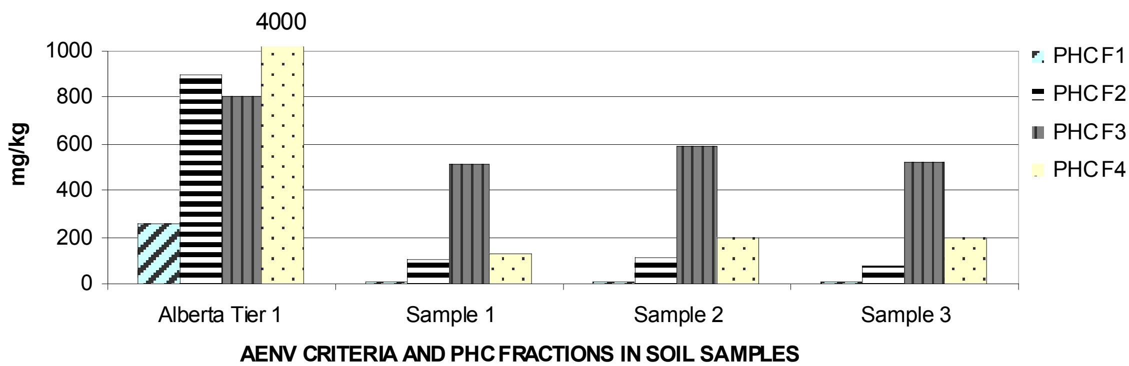
PARAMETER	Benzene	Toluene	Ethylbenzene	Xylenes	TPH
ALBERTA TIER 1 CRITERIA 1994	0.05	1.0	0.5	1.0	*1000
Sample 1	0.15	<0.02	2.17	<0.02	**2307**
Sample 2	0.05	1.56	0.57	9.91	**6170**
Sample 3	0.05	<0.02	1.60	1.99	**1036**

* TPH total petroleum hydrocarbons

Soils excavated were moved directly to the treatment area to minimize handling of impacted soils. Soils were placed in lifts approximately 0.30 m deep. This corresponds to the depth of the cultivator used to turn the soils. Turning was conducted approximately once every four weeks depending on weather conditions. Land treatment consisted of turning using a Caterpillar D5 Bulldozer equipped with a cultivator. Neither amendments nor nutrients were added to the treatment cells. No additional moisture was required to maintain the degradation process.

Samples were collected at regular intervals to monitor progress of remediation. Confirmatory samples generally indicated that BTEX constituents were below laboratory detection limits. Degradation of larger aliphatic hydrocarbons took longer than BTEX, but after 18 months analytical results indicated PHC fractions were below target criteria. Figure 1 shows Alberta Soil and Water Quality Criteria for Hydrocarbons at Upstream Facilities (AENV, 2001) and compares to PHC fractions in confirmatory soil samples analyzed and after remediaton was complete. Analytical results indicated that treated material met criteria for unrestricted land use. The length of time required to meet criteria was approximately 18 months.

Figure 1. Case I Comparison of Alberta 2001 Criteria and PHC Fractions After Land Treatment Complete.



Upon succesful treatment of materials reclamation was initiated. Reclamation consisted of deconstruction of berms and spreading out on the pad, then followed by replacement of topsoil. Site was recontoured to conform with the existing landscape. Revegetation was determined on landowner requests and to ensure that site was compatible with surrounding land.

Case Study 2 Biopiles - Passive Aeration Using Trackhoe Equipped With A Mixing Head Unit

Soils treated in this case were excavated during the remediation program conducted as part of decomissioning a well site in 1999. Preliminary remediation work was completed between December 1999 and May 2000. Soils impacted by salts and metals were excavated and hauled to a secure landfill. Laboratory results indicated that approximately 4,000 m^3 of soil were impacted with hydrocarbon based compounds only.

Light end fractions including benzene, ethylbenzene, xylene and TPH were above criteria.
Hydrocarbon impacted soils that were suitable for on-site treatment were stockpiled in a land treatment area approximately 25 by 75 m. Due to the nature of contaminants, and the quantity of material, remediation was conducted with the use of a trackhoe equiped with a mixing unit.

Analyses was conducted in the Fall 2000 prior to the implementation of the AENV 2001 guidelines. Consequently, analyses was compared to the Alberta Tier I Draft Criteria (AENV 1994) and Canadian Council of Ministers of the Environment Soil Quality Guidelines (CCME, 1999). TPH values ranged from 1,200 mg/kg to 1600 mg/kg, and benzene was reported at 0.33 mg/kg. It should be noted that confirmatory sampling was conducted after the AENV 2001 criteria was released; therefore the AENV Alberta Guidelines 2001 Tier I criteria was used to compare the results from this sampling event.

Soils were mixed with a trackhoe equipped with a mixing unit. At the time of mixing, amendments were added to ensure adequate nutrient levels in the soils. Once soils were mixed the material was placed in biopiles that ranged from 0.75 m to a maximum 1.5 m height. This ensured that diffusion was able to supply oxygen to the core of the biopile. No further aeration activities were conducted at this site.

Soil samples were collected from the treated area to confirm the success of the remediation program. The treatment pad was divided into sections and sampled according to sections. A composite sample was collected by sub-sampling the section and compositing together. In addition a discrete sample was collected from each section. A discrete sample was collected to ensure that volatile hydrocarbons were representative of site conditions. Samples analyzed had concentrations that were below target endpoints.

Table 2 summarizes the analyzed parameters of concern for the impacted soil. All analyzed parameters, except for the electrical conductivity were below criteria. This factor may be related to the high solubility of nitrogen fertilizers that were added at the time of remediation program. EC levels were about 2.90 dS/m in the confirmatory samples. Although it is above criteria, transformation of nitrogen ion to organic matter, and leaching due to rain events may reduce EC levels.

TABLE 2
Comparison of Confirmatory Soil Sample PHC Concentrations to AENV 2001 Criteria After Treatment Using a Trackhoe Equipped with a Mixing Unit.

Parameter	**Criteria**	**Section 1**		**Section 2**	
		Comp	**Discrete**	**Comp**	**Discrete**
Benzene	0.073	0.04	0.04	(0.02)	(0.03)
Toluene	0.86	<0.02	<0.02	(0.02)	<0.02
Ethylbenzene	0.19	0.05	0.04	(0.03)	<0.02
Xylenes	25	0.20	0.15	0.14	0.09
PHC (F1) (C_6-C_{10})	260	<20	NA	<20	NA

PHC (F2) (C_{10}-C_{16})	900	<10	NA	<10	NA
PHC (F3) (C_{16}-C_{34})	800	84	NA	260	NA
PHC (F4) (C_{34}-C_{50+})	4000	23	NA	280	NA

Remediation with a mixing head appears to have reduced the levels of contaminants to less than laboratory detection limits for BTEX, and below criteria in the cases of PHC fractions F1 to F4. Although the pathway of contaminant reduction occurred was not evaluated, it is possible that volatilization may have played a role in this case. Addition of nutrients may have enhanced the biodegradation processes as well.

Summary

In both case studies analytical results indicated soils had been impacted with facility related hydrocarbons. On site treatment reduced hydrocarbon concentrations below criteria, and allowed land to be returned to unrestricted used when final reclamation takes place. On site treatment reduced traffic on lease roads and transporting waste to different facilities. Treated materials were disposed of on site.

Comparison of cost will vary based on distance to facilities such as landfill, equipment availability and variable factors such as fuel and labor cost. When considering the treatment options, project managers need to evaluate the amounts of waste material available for treatment. Hauling to landfill requires trucking which will vary depending on distance travelled. However, this option allows for the most rapid solution. In cases of small quantities, this option may be cost effective.

On site treatment with engineered systems such as thermal desorption also allow for rapid treatment of impacted materials. Trucking to a centrallized facility may be required or construction of a pad to hold thermal desorption unit may take place on site. Engineering controls may be required to control emissions. In addition, screening out large cobbles may be difficult in gravelly material. For thermal desorption to be effective, larger quantities are required.

Bioremediation cost vary significantly, since equipment used will dictate cost of remediation. Using farm equipment to cultivate may work in a limited number of cases. Generally, specialized equipment is used to treat the impacted sediments. Construction of a compacted clay pad 50 m by 120 m can cost less than $10, 000. However, turning cost will depend on size of machinery and fuel costs. Bioremediation costs are similar to landfill and thermal desorption cost. When considering a treatment option land managers need to consider time frame, liability and convenience in deciding on which remediation option to choose.

Land treatment or bioremediation are often used when dealing with quantities that can be handled on the existing lease. Between 5,000 and 10,000 tonnes of material have been treated on site. When amounts of material to be treated cannot be handled at one time, it may be necessary to consider other options. In cases where landowner wants resolution in a short time frame, alternative options may be more suitable.

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