BIOREMEDIATION: INNOVATIVE APPLICATIONS OF AN ESTABLISHED TECHNOLOGY[1]

by

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Abstract. Bioremediation of organic wastes, pioneered by John Bogart, has been refined and modified extending the range of materials treated and decreasing the required treatment time. Materials degraded by biological methods include: oil and grease, petroleum hydrocarbons, creosote, pentachlorophenol, pesticides, PCB's, refinery wastes, and chlorinated solvents. These materials have been treated in waste sludges, contaminated soils, contaminated groundwater, process waters, and process sludges.

Additional Key Words: bioremediation, soils, sludges, organics, PNA, PCB, chlorinated solvents.

Introduction

Landfarming, long a staple in oil field and refinery remediation projects, was the genesis of bioremediation. Bioremediation has been expanded to encompass the remediation of sludges and groundwater. Traditional landfarming has undergone significant enhancements which have produced kinetic rates that are orders of magnitudes greater than those previously attained.

John Bogart, a bioremediation pioneer, has produced innovative biotechnology developments. These advances have extended both the range of compounds amenable to biotechnology and the rates of degradation achieved. These innovations include a patented technology, liquid-solids contact digestion; enhanced landfarming techniques; and hardware used in the remediation of groundwater and contaminated soils.

Materials degraded include oil and grease, petroleum hydrocarbons, creosote, pentachlorphenol, pesticides, PCB's, and refinery wastes. Ideal candidates for remediation include drilling muds, production pits, and oil shale residues. Spill sites have also been successfully restored.

Bioremediation is practical for sludges, contaminated soils, contaminated groundwater, process

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waters, and process sludge from industrial waste water treatment systems. Bioremediation has been demonstrated to be technically feasilble. Bioremediation is cost-effective, with unit prices often less than one-half of alternative remedies.

Landfarming

Landfarming of contaminated materials has come into difficult days. Some practitioners of the art/science have produced a general skepticism regarding all bioremediation. The methods employed by these groups have simply failed to achieve detoxification at best, and increased the volume of contaminated material at worst. Some regulators feel that the "land ban" has doomed landfarming to join blood letting as an abandoned practice.

The purpose of this report is not to defend nor bemoan the status of landfarming, but to report on innovative alternatives to the traditional practice. Much land-treatment is continuing and with reasonably satisfactory results. Some of these practices will be surveyed.

Several land-treatment facilities, under the direction of John Bogart, have achieved acceptable, reproducible results on woodtreating wastes. All of these systems were operated inside the existing impoundment and on a clay liner. The USEPA is requesting (mandating?) synthetic liners to assure the policy of "no migration" in accordance with the Resource Conservation Recovery Act (RCRA).

The Bogart system incorporates inoculation with natural organisms into a program of active aeration and soil moisture control. Some representative data from landfarming operations is summarized in Table 1.

Other problems, in addition to the concern of "migration" of contamination, complicate land-treatment projects. The kinetic rate of biodegradation in a "moist" environment is slow, at best. If the matrix becomes totally dry the bacteria become inactive. Maintaining optimum moisture levels is difficult if not nearly impossible in a large scale operation. Too much moisture produces anoxic or anaerobic conditions and is as detrimental to bioactivity as too little moisture. Weather, then, plays a vital, unpredictable, and virtually uncontrollable role in solid state biotreatment.

Table 1
Landfarm Data

SITE	PARAMETER	INITIAL (mg/kg)	FINAL (mg/kg)	TIME
A	K-001	6,959	58	1 month
A	Pentachlorophenol (PCP)	1,291	9.3	1 month
B	K-001	6,582	210	1 month
B	Pentachlorophenol (PCP)	1,184	ND	1 month
C	K-001	12,561	835	5 weeks
C	Pentachlorophenol (PCP)	1,336	104	5 weeks
D	Benzene	38.1	.003	3 weeks
D	Toluene	266.9	<.001	3 weeks
D	Ethylbenzene	74	.002	3 weeks
D	Dichlorobenzene	29.1	.011	3 weeks
D	Xylene	303.1	.03	3 weeks
E	K-001	2,050	106	1 month

Besides being slow and unpredictable, landfarming also suffers from the "hot" spot syndrome. One area may be decontaminated to Best Demonstrated Available Technology (BDAT) levels or below while a neighboring sector remains extremely contaminated. Verification sampling programs must be carefully devised and implemented to assure satisfactory remedial actions.

Liquid/Solids Contact Process

The twin problems of moisture control and lack of homogeneity were overcome by the liquid/solids contact (LSC) process. Producing an aerated slurry coincidentally addresses both problems. The constantly mixed slurry is homogeneous. This insures a uniform degradation throughout the contaminated matrix.

Aerating the slurry provides high levels of oxygen required for the biological oxidative processes. Reaction rates are maintained at a high level in this aerobic environment. Appropriate biological enhancements such as nutrients, pH control, emulsifiers, and even co-metabolites are easily and conveniently administered in a uniform manner.

The LSC has successfully reduced both volume and toxicity of 50% organic sludges classified as K-001 or woodtreating wastes consisting of creosote and pentachlorophenol. One specific project in Sweetwater, Tennessee, involved 4500 cubic yards of sludge. The residuals, following degradation, were estimated to be between 9 and 15 cubic yards by two independent consulting engineering firms. (Bogart directed project: Langdale Forest Products, Valdosta, Georgia.)

The final residue was analyzed and the individual K-001 constituent levels were below 10 ppm. This treatment was conducted at a rate of 100 cubic yards per week. Additional reactors can be employed to increase the throughput rate.

The LSC process has been used to remediate sites contaminated with oil and grease, such as in oil drilling locations in Louisiana. Three specific sites yielded the following oil/grease data.

Table 2
Oilfield Waste Biodegradation

	Site A	Site B	Site C
Initial	19.5%	28.89%	3.10%
Final	.4%	.97%	.38%
Reduction	98%	97%	88%

Refinery and manufacturing wastes have been degraded to acceptably low levels in Louisiana and Georgia. Compounds degraded in full-scale projects include, in addition to those mentioned earlier, dichloroethane, styrene, vinyl chloride, and other PNA's. See Table 3.

Laboratory simulations of the process have produced remarkable reductions of chlorinated compounds including pesticides, herbicides, and even PCB's. The PCB data is

Table 3
Biodegradation of Petrochemical Contamination

Compound	Initial (mg/l)	Final (mg/l)	Reduction
Styrene	600	.05	100%
Vinyl Chloride	1.4	.035	97.5%
Organics (PNA's)	81,069	19.4	99.8%

included in Table 4. Perchlorethylene, dichloroethane, and trichloroethylene were also degraded. Simple compounds, such as petroleum hydrocarbons and alcohols are literally "bug bait."

There is one problem engendered by the LSC process. That problem relates to large volumes of inert materials, i.e. soils, in the slurry system. Maintaining an optimum, that is aerobic, environment requires that the soils be turned or stirred every 15 minutes if not totally suspended. The size and configuration of the reactor are as critical to this process as is the raw horsepower requirements.

Placing significant amounts of soil into large in-ground reactors precipitates, literally, problems. The mud settles to the bottom and refuses to be cleaned. The bacteria quickly use the available oxygen, and since more oxygen cannot penetrate the mud matrix, the bacterial system becomes anaerobic, and treatment terminates.

A coincidental problem is how to get the soil out of the treatment cell once it has been decontaminted. The answer to both problems is simple: horsepower. The slurry can be suspended by using additional mixers in the reactors. Once treated, this slurry can be pumped out of the reactors and dewatered.

One additional caveat must be posited. Particle size must be carefully monitored. Small stones will be pumped into the cell, settle to the bottom and stay there. Most mixing systems will not suspend the rocks and they will eventually fill the treatment system.

Slurry Reactors

An alternative solution, has been developed which involves controlling reactor size and mechanical action to maintain the slurry. Auxiliary hardware assures appropriate particle size. The initial operations include a power screen operation to remove rocks and debris. This step also pulverizes clods. The fine material is then slurried and passed through a slurry grinder before being introduced into the reactor.

A combination of mixing aerators and slurry circulation techniques maintains the suspension. This affords an opportunity for the bacteria to literally "eat" the contaminant from the soil particles. Decontamination is therefore rapid and complete.

Some initial data are available. Pilot runs were conducted on heavy clay soils in June and July of 1988. The average contamination levels were 15,000 mg/kg of creosote components. Individual samples varied from 10,000 mg/kg to 18,300 mg/kg to 27,800 mg/kg.

Three different cells were operated and sampled. The data are summarized in Table 5. Data are given in mg/kg.

Table 4
Biodegradation of PCB's

Parameter	Initial (mg/kg)	Final (mg/kg)	Reduction	Time
PCB	540	8.2	98.5%	144 hours
Arochlor 1254	6,365	120	98%	10 days
Arochlor 1260	16,975	5	99.9%	6 days
Arochlor 1254 (oil)	20,000	30	99.8%	21 days

Table 5
Biological Decontamination
In Slurry Reactor
(Creosote)

Time	Cell 1	Cell 2	Cell 3
Initial	11,414	5,571	9,284
1 week	250	299	30
2 weeks	195	129	4
Reduction	98.3%	98.7%	99.96%

Clays are more difficult to remediate than sandy soils. The contamination is virtually "washed" off of the sand. The clay adsorbs the contaminant and holds it tightly. Thus the requirement for the slurry-state biodegradation as opposed to merely "washing" it.

Groundwater

Biotechnology has been extended to groundwater remediation. A groundwater remediation unit (MiKIE) has been developed and application for patent has been made. The unit uses the basic principles of bioremediation previously outlined. The system employs pump and treat methodology.

Data from two sites are outlined here. Site A was monitored from August 18 through December 14, 1987. Of the 17 effluent analyses, only one had a detectable quantity of pentachlorophenol (PCP). It registered 0.21 mg/l.

Site B was definitely more highly contaminated with one sample of raw water being analyzed as containing 1,730.26 mg/l PCP. Monitoring from April 29 through December 14 yielded nine nondetectable (ND) samples and seven that ranged form 1.09 to 6.77 mg/l PCP.

Progressive samples were taken toward the end of this period and those data are summarized in Table 6. Dates are input sample (I) and output sample (O). Residence time for samples was one day.

Maintenance of a constant feed stream would level out these fluctuations. The data listed in the table are not consecutive. They were interspersed throughout the time period and the feed stream was constantly changing in concentration. The level of detection was .01 mg/l. Therefore, the ND samples contained less than .01 mg/l.

The MiKIE is also being used to treat process waste streams from plants and refineries. The effluent from these systems is being discharged to a local sanitary sewage system.

Table 6
Bioremediation of Groundwater Contamination

Sample	Input (mg/l)	Output (mg/l)	Dates -	In	Out
1.	227.57	ND	Aug.	18	19
2.	48.90	2.09	Oct.	4	5
3.	39.16	2.09	Oct.	27	28
4.	31.49	ND	Nov.	1	2
5.	9.87	.49	Nov.	8	9
6.	12.81	ND	Nov.	15	16
7.	19.77	ND	Nov.	22	23
8.	13.81	ND	Nov.	29	30
9.	9.12	ND	Dec.	13	14

Summary

Bioremediation has been expanded to cover waste sludges, process sludges, contaminated soils, contaminated groundwater, and process water from active plants. Traditional bioremediation techniques have been supplemented and in some cases supplanted by newer technologies.

The handicaps of landfarming have been overcome by the slurry system of treatment. The system is most conveniently and efficiently conducted in specially designed reactors available now. These reactors have been field tested and demonstration data verifies the utility and efficiency of the system.

The cost of bioremediation is site, contaminant, and matrix dependent. General ranges for soil remediation vary from $60 to $80 per cubic yard in the slurry system. Landfarm costs vary from $30 to $40 per cubic yard. Water remediation will average 60¢ per 1000 gallons.

Bioremediation techniques have been applied to nearly every known organic contaminant. Because the contaminant is actually being destroyed, bioremediation is superior to landfilling. In many cases, destruction efficiencies rival those of incineration. Biodegradation is moving toward the designation as treatment of choice.
