ELSEVIER Journal of Hazardous Materials 40 (1995) 165–173

JOURNAL OF HAZARDOUS MATERIALS

Evaluation of the BioGenesis^{SM} soil washing technology

Annette Gatchett[a], Pinaki Banerjee[b]

[a] *US Environmental Protection Agency, Risk Reduction Engineering Laboratory, Superfund Technology Demonstration Division, 26 W. Martin Luther King Drive, Cincinnati, OH 45268, USA*

[b] *PRC Environmental Management, Inc., 1921 Rohlwing Road, Rolling Meadows, IL 60008, USA*

Received 9 December 1993; accepted in revised form 25 May 1994

Abstract

The BioGenesis Enterprises, Inc. (BioGenesis) soil washing technology was demonstrated as part of the US Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) program in November 1992. The demonstration was conducted over three days at a petroleum refinery where soils were contaminated with crude oil. The BioGenesis soil cleaning process consists of two stages. In the first stage, contaminants are transferred from the soil matrix to a liquid phase using a proprietary surfactant solution. In the second stage, the surfactant solution enhances biodegradation of residual contamination in soil.

For the SITE demonstration, three runs were conducted over three days, each treating 18 cubic yards of soil. Based on chemical analyses conducted on soils collected prior to the demonstration, total recoverable petroleum hydrocarbon (TRPH) was selected as the parameter of concern for the SITE demonstration. TRPH concentrations were monitored in treated and contaminated soils, water, and wastewater. Results of chemical analyses show that TRPH levels decreased by 65–73% in washed soils. The TRPHs in residual soils indicate that soil washing and biodegradation together removed 85–88% of TRPH after 120 days. The treatment system's performance was found to be reproducible at constant operating conditions.

This paper presents an introduction, a technology description, the experimental design of the SITE demonstration, SITE demonstration results, and conclusions.

1. Introduction

The BioGenesis^{SM} soil washing technology was developed to remove organic compounds from soils and sediments. The technology uses the BioGenesis^{TM} cleaner, a proprietary solution, to transfer organic compounds from the soil matrix to a liquid phase. In the liquid phase, contaminants are either dissolved or are sorbed onto suspended particulates. Soil washing technologies, in general, can potentially treat a wide variety of contaminants such as heavy metals, halogenated solvents,

* Corresponding author. Tel.: 513 569-7697. Fax: 513 569-7620.

SSDI 0304-3894(94)00065-0

aromatics, gasoline, fuel oils, polychlorinated biphenyls (PCBs), and chlorinated phenols [1].

The BioGenesis^{SM} technology was evaluated during the SITE demonstration to determine its ability to extract TRPHs from soil. The objectives for the project were: (i) determine removal efficiencies for TRPHs in the treatment system; (ii) evaluate whether or not the treatment system's performance is reproducible at constant operating conditions; (iii) gather information necessary to estimate treatment costs, including process chemical dosages and utility requirements; (iv) obtain information on biodegradation of TRPHs in treated soil by monitoring TRPH concentrations in the treated soil over a period of time.

2. Technology description

The BioGenesis^{SM} soil washing technology involves high-energy mixing of excavated, contaminated soils in a mobile washing unit. The technology consists of a two-stage process. In the first stage, a proprietary solution, the BioGenesis^{TM} cleaner, is used to transfer organic compounds from the soil matrix to a liquid phase. The second stage involves enhanced biodegradation of residual soil contamination and contaminant-rich wastewater.

The BioGenesis^{SM} soil washing technology can be used as a stand-alone technology because it includes enhanced biodegradation to reduce the residual contaminant levels and toxicity of washed soils. Soils containing sand and other coarse materials are generally the most ideal for soil washing treatment. Soil containing large amounts of silt, clay, and humic substances, and soils with high total organic carbon (TOC) content are not treated as effectively by most soil washing technologies. However, BioGenesis claims that its technology may be effective for soils containing a high percentage of silt and clay. The BioGenesis technology also does not require the screening of particles larger than 4–6 in. in diameter. However, to ensure representative sampling for monitoring purposes, it is preferable to screen out large particles because contaminants associated with large particles are usually minimal.

According to the developer, BioGenesis^{SM} cleaner is rapidly biodegraded by common soil microbes and stimulates microbial activity, which biodegrades residual soil contamination not removed by the wash solution. According to the material safety data sheet (MSDS) provided by BioGenesis, none of the constituents of the cleaner are defined as a Resource Conservation Recovery Act (RCRA) or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) hazardous waste or hazardous substance.

The products of the soil washing process are treated soil, contaminated wastewater, sediment in wastewater, and an oil–water mixture. Treated soil can be stored in roll-off bins, and the contaminants are allowed to biodegrade prior to disposal. The oil–water mixture is recovered for off-site disposal or reuse. Contaminated wastewater can be treated separately using aerated bioreactors or by conventional water treatment systems.

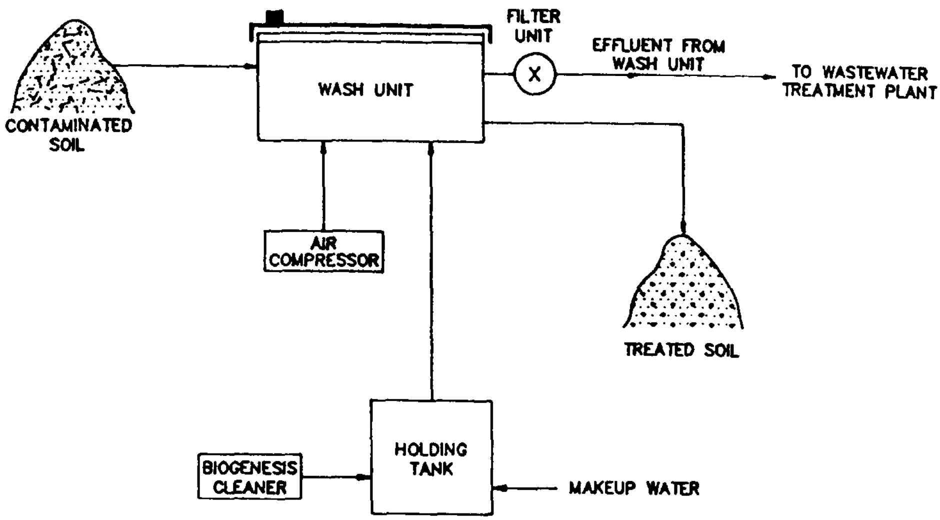

Fig. 1. Schematic diagram of BioGenesis treatment system.

A schematic diagram of the BioGenesis^{SM} treatment system is shown in Fig. 1. The principal component of the treatment system is the washing unit. The unit currently being used is 24 ft long, 7 ft wide, and 5 ft deep, with overflow channels 1 ft deep. The unit has a perforated base to introduce air for mixing and to drain wastewater. It is equipped with a shaker mechanism (three units on each side of the wash unit) for agitating the soil slurry to enhance mixing.

3. Experimental design of the site demonstration

The SITE demonstration refinery is active. Approximately 2000 cubic yards of soil at the refinery were contaminated with crude oil, as indicated by high concentrations of TRPH reported at levels of up to 30,000 mg/kg. Results of soil analyses indicate that all other chemicals, including volatile organic constituents (VOC), were either not detected or were present at low levels in untreated soil.

Three runs were conducted on three different batches of 18 cubic yards of soil at the refinery over 3 days. Each batch of soil was washed twice with water containing the BioGenesis^{SM} cleaner at a temperature of 60 °C. Mixing time, solution concentration, and mixing intensity were kept at constant operating conditions. TRPH concentrations in treated and contaminated soils, water, and wastewater were monitored. Other parameters monitored included percent moisture of soils, metals concentrations, pH, particle size distribution, TOC content of selected soil samples; volume and density of untreated soils; and total suspended solids (TSS) of wastewater samples. Metals concentrations were monitored to determine toxicity potential to microorganisms. Percent moisture, TOC content, particle size distribution, and pH were monitored to determine the physical and chemical characteristics of the soil that may affect treatment. Volume and density were monitored to determine the quantity of soil treated. The amount of solids transferred to the liquid phase was determined by monitoring TSS in wastewater.

Although wastewater samples were collected during the demonstration, some wastewater was discharged directly into drains leading to the refinery's wastewater-treatment system. A mass balance of TRPH in the system was not achievable because the volume of wastewater was not measured. TRPH concentrations in the plant water used for washing and in the BioGenesis cleaner were either at low levels or below detection limits and were not expected to affect TRPH levels in soils.

Treated soil from Runs 2 and 3 were collected in 5-gallon buckets and stored at 20 °C in a laboratory for monitoring over a period of time. Samples were collected from the buckets on Day 14, Day 40, Day 60, Day 90, Day 120, and Day 180 after soil washing to determine the extent of biodegradation in treated soil.

An economic analysis was conducted to determine the costs associated with treatment by the BioGenesis^{SM} soil washing technology. A number of factors affect the estimated costs. These factors include type and concentration of contaminants, treatment goals, volume of contaminated soil, physical site conditions, geographical site location, site accessibility, and availability of utilities. Ultimately, the characteristics of residual wastes produced by the BioGenesis^{SM} system affect disposal costs because they determine if the residuals require either further treatment or permit off-site disposal.

Cost data associated with the BioGenesis^{SM} soil washing technology are presented in Table 1 and have been assigned to the 12 categories applicable to typical cleanup activities at Superfund and RCRA sites [2]. These cost categories include the following: (1) site preparation; (2) permitting and regulatory requirements; (3) capital equipment; (4) startup; (5) labor; (6) consumables and supplies; (7) utilities; (8) effluent treatment and disposal; (9) residual waste shipping and handling; (10) analytical services; (11) maintenance and modifications; and (12) demobilization. Table 1 presents the total fixed and variable costs per cubic yard of soil treated. The wash unit to be used by BioGenesis at different sites is the same. However, in order to provide useful data, the economic analysis presents the costs for a 500, 1000, and 2000 cubic yard soil washing project. It should be noted that for several categories, the volume of soil to be treated is not linearly related to cost. For example, personal protective equipment (PPE) consumption is based on time, which is related to the number of days for treatment. Therefore, consumable and supply costs associated with PPE and the number of drums needed for disposal of PPE may not be linearly related to the amount of soil treated. Residual and waste shipping and handling include disposal of wastewater. Due to recycling of wastewater, 3000 gallons will require disposal at the end of treatment. Costs associated with this activity, therefore, will not change for treating different amounts of soil. The estimated cost per cubic yard of soil treated during the SITE demonstration is $74–$160.

Table 1
Costs associated with the BioGenesis[SM] soil washing technology[a]

Cost category	Volume of soil treated (cubic yards)		
	500	1000	2000
Site preparation[b]	\$20,800	\$22,300	\$24,200
Permitting and regulatory requirements[b]	10,000	10,000	10,000
Capital equipment[b]	21,560	27,790	40,250
Startup[b]	0	0	0
Labor[b]	7600	12,200	22,000
Consumables and supplies[b]	1300	2200	4900
Utilities[c]	530	870	1600
Effluent treatment and disposal[c]	0	0	0
Residual and waste shipping and handling[c]	15,900	24,100	40,300
Analytical services[c]	1300	2300	3300
Maintenance and modifications[c]	0	0	0
Demobilization[b]	1000	1000	1000
Total fixed costs[a]	\$53,360	\$61,090	\$75,450
Total variable costs[b]	\$26,630	\$41,770	\$72,100
Total cost per cubic yard treated	\$160	\$103	\$74

[a] Costs are based on February 1993 dollars.
[b] Fixed costs.
[c] Variable costs.

4. Site demonstration results

Metals concentration data from the demonstration show that metals were present at levels generally found in natural soils and were not expected to be toxic to microorganisms. Metals concentrations in the treated and untreated soils did not, and were not expected to, reflect any discernable effect of soil washing because metals were not targeted for treatment by a metal washing surfactant blend. TOC content and pH, which were analyzed at the start of each run, showed comparable values between runs. TOC content values, which ranged from 1.6% to 1.8%, indicate that petroleum hydrocarbons would strongly sorb onto soil. These TOC content values, however, are comparable to values generally found in surface soils. The pH in untreated soils was near neutral and was not expected to affect the treatment process. Soil at the refinery, on the average, contained 13% gravel, 76% sand, 6% silt, and 5% clay.

Average TRPH concentrations in treated and untreated soils are summarized in Table 2. Table 2 shows that TRPH removal during Runs 1, 2, and 3 was 65%, 73%, and 72%, respectively, indicating that the BioGenesis[SM] treatment system's performance is reproducible at constant operating conditions.

The BioGenesis[SM] treatment system also enhances biodegradation in treated soil. The SITE demonstration was conducted in November when temperatures at the site were near 0 °C. Because the temperature at the site was expected to be near or below

Table 2
Average TRPH concentrations in untreated and washed soils, mg/kg

Run number	Untreated soil	Treated soil	Percent removal
1	7666	2650	65
2	7567	2033	73
3	9933	2833	72

Table 3
TRPH concentrations in treated soil, mg/kg

Run and day	Sample 1	Sample 2	Sample 3
Run 2			
Day 0	2100	2000	2000
Day 14	2200	2100	2600
Day 40	2000	2000	2000
Day 60	1600	NA[a]	NA[a]
Day 90	1100	970	1000
Day 120	980	920	970
Day 180	1060	1100	1000
Run 3			
Day 0	2700	2900	2900
Day 14	3100	3200	2900
Day 40	2600	3300	2700
Day 60	2100	NA[a]	NA[a]
Day 90	1500	1400	2300
Day 120	1200	1100	1000
Day 180	1380	1590	1390

[a] NA = Not available.

freezing, biodegradation of contaminants in the treated soil pile at the site was expected to proceed slowly. Therefore, the biodegradation study was conducted in a laboratory. Results of TRPH analyses are presented in Table 3. Average TRPH concentrations in these samples are plotted in Fig. 2. Table 3 and Fig. 2 indicate that TRPH concentrations increased in samples collected on Day 14 compared to those collected from washed soil on site during the demonstration. TRPH levels, however, decreased in samples collected on Day 40 to levels within 1% of those detected at the beginning of the laboratory biodegradation study. Differences in TRPH levels between Day 0 and Day 40 are probably due to analytical and sampling variabilities. TRPH concentrations decreased in all samples collected after Day 40, indicating that the microorganisms required an acclimation period. For Run 2, TRPH concentrations decreased in all samples collected on Day 90 by approximately 50%, decreased further in samples from Day 120, and then increased in Day 180 samples. For Run 3,

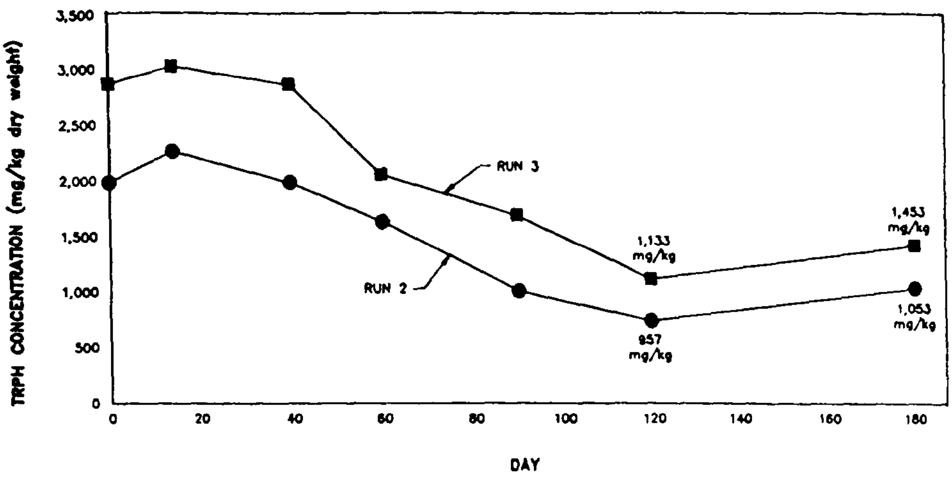

Fig. 2. Biodegradation results; TRPH concentrations from treated soils over time.

TRPH levels continued to decrease up to Day 120, and then increased in samples from Day 180. Soils in the laboratory study were not mixed, and nutrients or moisture were not added after Day 0. Analytical and sampling variabilities account for the fluctuation in concentration between Day 90, Day 120, and Day 180 samples for Run 2 and Day 120 and Day 180 samples from Run 3.

BioGenesis claims that TRPH concentration monitored on site decreased to levels below 1000 mg/kg, a level required by its contract with the refinery. Additional surfactant solution was added to soils collected at the beginning of the biodegradation study. BioGenesis, however, added surfactant solution again after 120 days to on-site soils. BioGenesis believes that during the laboratory biodegradation study, biodegradation was inhibited between Days 120 and 180 because of nutrient limitations.

Results of TRPH concentrations in untreated soils after washing from Run 1 and after washing and biodegradation up to 120 days from Runs 2 and 3 are plotted in Fig. 3. Soils from Runs 2 and 3 show removal efficiencies of 83% and 88%, respectively, from the washing and biodegradation combination.

To confirm that a healthy population of microorganisms capable of degrading crude oil was present in the treated soil, samples collected on Day 90 were characterized for bacterial population. Samples were analyzed to determine the population of aerobic heterotrophic bacteria that require organic compounds for growth and reproduction. The population of aerobic heterotrophic bacteria in these samples ranged between 7.3×10^7 and 1.3×10^8 colony forming units per gram (CFU/gm). Petroleum aerobic hydrocarbon-utilizing bacteria, a type of heterotrophic bacteria that can degrade petroleum hydrocarbons, were also analyzed. The population of hydrocarbon utilizing bacteria in these samples ranged between 5.7×10^6 and 1.1×10^7 CFU/gm.

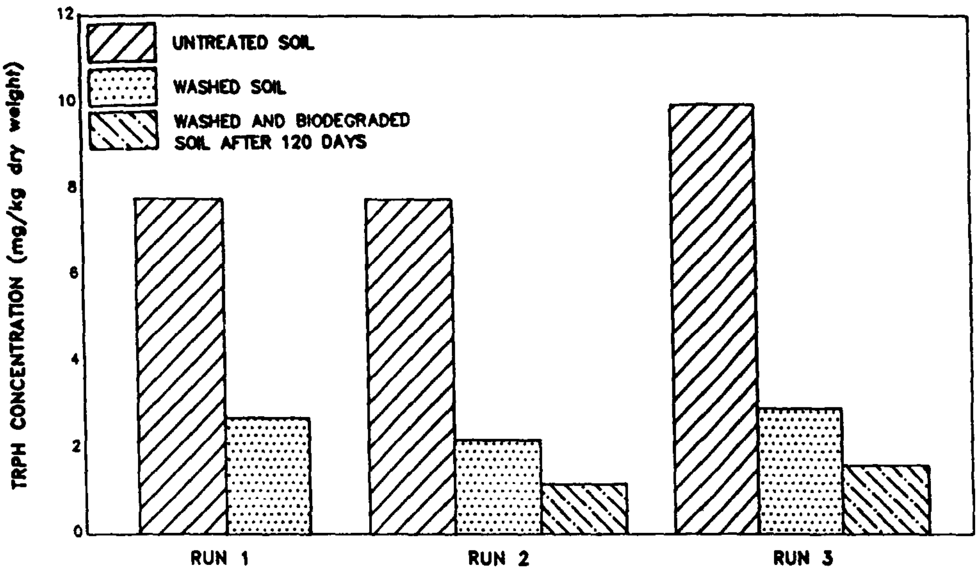

Fig. 3. Average TRPH concentrations in treated and untreated soils.

In general, no major differences were observed in the colony appearance or morphology of the soil samples. The same type of organisms was present in each sample. The number of different types of colonies, or colony diversity, was high, indicating that the population was healthy and not dependent on one dominant organism. The bacterial analysis indicated the presence of a healthy and diverse bacterial population well acclimated to hydrocarbons as a carbon source in the treated soil. A well established population is flexible and can easily reestablish its numbers when assaulted by pH shifts, temperature shifts, or chemical additions. The well established population also indicates that the BioGenesis^{SM} cleaner, the defoaming agent, and the degradation products of petroleum hydrocarbons are not toxic to the microorganisms.

5. Conclusions

Based on the SITE demonstration, the following conclusions may be drawn about the applicability of the BioGenesis^{SM} soil washing technology:

– Results of chemical analyses for soil samples collected from the refinery show that levels of TRPHs, an indicator of degraded crude oil, decreased by 65–73% in washed soils. After the TRPH in residual soils biodegraded for an additional 120 days, 85–88% of TRPHs were removed from treated soil.

– Results from the SITE demonstration show that the technology can successfully treat soil containing petroleum hydrocarbons. The treatment system's performance was found to be reproducible at constant operating conditions.

– The BioGenesis^{SM} treatment system processed crude oil contaminated soil at the refinery at a cost of 74 per cubic yard (based on the treatment of 2000 cubic yards of soil). Costs at other sites may vary depending on site characteristics.

References

[1] US Environmental Protection Agency, Engineering Bulletin: Soil Washing Treatment, EPA/540/2-90/017, September, 1990.

[2] G. Evans, Estimating innovative technology costs for the SITE program, J. Air Waste Manag. Assoc., 40(7) (1990) 1047–1051.