

BIOSOLIDS ENHANCED REMEDIATION

DRY BIODEGRADER ADDITIVE PROCESS DESCRIPTION

OVERVIEW

Innovative Remediation Technologies, Inc. (IRT) uses a bioremediation process that is unique to the industry. The Biosolids Enhanced Remediation (BER) approach takes advantage of aerobic and facultative metabolic pathways utilized by specifically cultured microorganisms and inoculation levels which far exceed the numbers of bacteria which can be typically attained by stimulating the natural population of selected hydrocarbon degraders. Moreover, the mechanical processing and subsequent addition of the appropriate nutrients and microbial cultures are the result of years of experience with soil handling equipment and bioremediation projects by IRT's personnel.

DESIGN PARAMETERS FOR DRY BIODEGRADER MIX

Bacterial Component

Dry bacterial inoculum is blended within a matrix of organic and inorganic macro and micro nutrients. A one time application of dry nutrients typically represents $>1 \times 10^8$ *contaminant degrading bacteria* per kg of soil. Due to the immediate availability of nutrients, food (organic contaminant in the soil) and contaminant degrading bacteria, the soil cleansing process begins immediately without the lag time associated with other such processes. Repeated additions of concentrated bacteria can be performed to enhance treatment time. This is typically done in cases where moisture levels have fallen below acceptable levels. The dominant bacteria used for remedial process have been identified as common, non-pathogenic soil bacteria and are given below. It should be noted that these organisms will typically be present within the target contaminated soil but in low numbers. These existing organisms will also begin to increase their numbers as nutritional requirements are met. The addition of bacteria to the soil is necessary primarily to decrease lag time as previously mentioned.

Pseudomonas putida

Corynebacterium aquaticum

Arthrobacter crystallopoietes

Pseudomonas aeruginosa

Alcaligenes xylosoxydans

Agrobacterium tumefaciens

Ochrobactrum anthropi

Pseudomonas alcaligenes

Macro and Micro Nutrient Component

In order for the bacteria to successfully metabolize organic contaminants, it is critical that the soil contain all of the necessary nutrients to accommodate growth. The micro-nutrients are comprised of B vitamins, magnesium, calcium, manganese, iron and others. Macro nutrients within the dry BioDegrader mix are comprised of ammonia nitrogen, nitrate nitrogen and ortho-phosphate. The concentrated organic nutrient components within the BioDegrader are contained within kiln dried and disinfected poultry manure. The primary macro nutrients, consisting of ammonia nitrogen and ortho-phosphate, are supplied from technical grade sources. These components are essential for efficient cell growth and maintenance. Nitrate nitrogen is also added as a component as a means of allowing for metabolism to continue in the absence of oxygen within contaminated soil piles.

The formulation for the usage of macro nutrients by the organisms that degrade target contaminants is given below. Biomass is represented as $C_5H_7O_2N$. The contaminant is represented as $C_{13}H_{28}$. Similar equations can be solved for other organic contaminants with fewer or greater numbers of carbons such as gasoline, kerosene, motor oil, or heavy oils. Innovative Remediation Technologies, Inc. manages the nutrient requirements stoichiometrically as follows.

The equations that demonstrate the chemical requirements for biological treatment are derived from the combination of the half reactions associated with bacterial systems. A balanced chemical reaction for a given biological conversion is useful in obtaining a mass balance. This equation is generally written as follows.

$$R = f_s R_c + f_e R_e - R_d$$

R_c = the half reaction for synthesis of bacterial cells ($C_5H_7O_2N$)

R_e = the half reaction for the electron acceptor

R_d = the half reaction for the electron donor

f_s = the portion of the electron donor used for cell synthesis

f_e = the portion of the electron donor used for cell energy, i.e., maintenance

Aerobic Mass Balance:

$f_s = 0.7$ using oxygen as the electron acceptor

$f_e = 0.3$

$f_s R_c$: $0.14 CO_2 + 0.035 HCO_3^- + 0.035 NH_4^+ + 0.7 H^+ + 0.7 e^- = 0.035 C_5H_7O_2N + 0.315 H_2O$

$f_e R_e$: $0.075 O_2 + 0.3 H^+ + 0.3 e^- = 0.15 H_2O$

$-R_d$: $0.01236 C_{13}H_{28} + 0.3267 H_2O = 0.1609 CO_2 + H^+ + e^-$

$R = 0.01236 C_{13}H_{28} + 0.075 O_2 + 0.035 NH_4^+ + 0.035 HCO_3^- = 0.0209 CO_2 + 0.1383 H_2O + 0.035 C_5H_7O_2N$

Facultative Mass Balance:

$f_s = 0.6$ using nitrate as the electron acceptor

$f_e = 0.4$

$f_s R_c$: $0.12 CO_2 + 0.03 HCO_3^- + 0.03 NH_4^+ + 0.6 H^+ + 0.6 e^- = 0.03 C_5H_7O_2N + 0.27 H_2O$

$f_e R_e$: $0.08 NO_3^- + 0.48 H^+ + 0.4 e^- = 0.04 N_2 + 0.24 H_2O$

$-R_d$: $0.01236 C_{13}H_{28} + 0.3267 H_2O = 0.1609 CO_2 + H^+ + e^-$

R : $0.01236 C_{13}H_{28} + 0.08 NO_3^- + 0.03 HCO_3^- + 0.03 NH_4^+ + 0.08 H^+ = 0.0409 CO_2 + 0.1833 H_2O + 0.04 N_2 + 0.03 C_5H_7O_2N$

BioDegrader addition to the soil may be modified based primarily upon soil analytical data for nitrogen and phosphorus. Repeated applications of BioDegrader are sometimes carried out as indicated by testing to keep the process moving forward at a steady rate.

Certain knowledge of the fate of nitrogen and phosphorus within the soil matrix is essential to understanding the control of such nutrients when used during the remedial processes. Ammonia nitrogen within the dry BioDegrader is added at an initial concentration sufficient to satisfy the aerobic biodegradation equation. However, ammonia nitrogen is taken up by microorganisms during the process of cell synthesis (growth). This newly formed organic nitrogen may be recycled within the soil during cell growth and death, but will not be expressed as ammonia nitrogen in nutrient analyses since it has taken an organic form.

Nitrate nitrogen may be consumed by bacteria in two ways, assimilation and dissimilation. Certain soil microbes have the ability to utilize nitrate nitrogen in the same manner as ammonia nitrogen. However, in most cases nitrate nitrogen serves as the final electron acceptor (replacing oxygen) as shown in the equation for the facultative destruction of organic contaminants. Nitrate nitrogen is not recycled within the soil in this process, but converted to nitrogen gas and released to the atmosphere. Therefore, nitrate is consumed during the remedial process and may be controlled based upon contaminant concentration and appropriate addition rates. This requires an efficient monitoring and control process. However, nitrate concentrations can be reduced or eliminated from the treatment in situations where this is a concern. The aerobic pathway would then become the primary remedial technique and regular soil mixing would become a requirement.

Ortho-phosphate is the most essential nutrient, although required in the least amounts. It is critical to cell metabolic functions due to its role in ATP and ADP energy transformations. Ortho-phosphate is used rather than other forms of inorganic or organic phosphorus due to its ability to be rapidly taken up by microbial cells. Other forms most always require transformation in the soil matrix before utilization can occur. However, it is important to note that most forms of phosphorus are quickly bound to the soil and are not available for leaching. This is why it is critical to insure that the nutrients, the specific organisms and food (contaminant) are in contact instantaneously.

OPERATING PARAMETERS

Biological

Certain operating conditions are required to insure that biodegradation takes place effectively. Proper nutrients, bacterial culture, moisture, temperature and pH are most important. The proper nutrients and bacterial culture addition have been previously described. Moisture within the soil piles is critical to maintaining viable bacterial cultures. Existing soil moisture, typically 16-22%, is usually sufficient to maintain biological activity. Temperature dictates the level of biological activity, that is, the higher the temperature the greater the biodegradation rate. The cultures used as inoculum have enzyme systems that are active between 35 F and 120 F with an optimum around 80 F.

Bioremediation activities for all practical purposes should be conducted outdoors only as temperatures rise above 40 F. During cold weather reciprocating blowers are often used to blow warm air into biotreatment piles to help overcome temperature deficiencies.

Likewise, pH is important for efficient biodegradation. The enzyme systems of most contaminant degrading bacteria operate at their optimum between pH 6.0-8.0. The nutrients that are added to the soil during normal processing are generally sufficient to buffer against any pH drop that may occur as a result of biological activity. When moisture levels fall below acceptable levels, additional moisture must be added.

Soil Handling and Processing Overview

Contaminated soil is fed through a soil screen with a hammermill or pug mill which effectively reduces the soil particle size to approximately one inch. BioDegrader solids are added on the exit conveyor in the case of the soil screen and prior to the auger for pug mills. The process is designed to add contaminant-degrading bacteria in excess of the numbers of bacteria that could typically be grown naturally in the soil under normal conditions. The process is also designed to provide all of the necessary vitamins and minerals necessary to accomplish complete metabolism of the target contaminants. However, the BioDegrader additive can only be successful by contacting the ingredients directly with the target contaminants. Therefore, aggressive soil mixing is critical to the overall success of the process. Innovative Remediation Technologies, Inc. is not aware of any other bioremediation company that has implemented this strategy.

Once the food source (contaminant) has been metabolized by the bacteria, the population of organisms begins to die off until a normal background level of organisms remains which would be supported by available food sources.

Soil Pile Design

Once the soil has been excavated and treated by the BER process, it is placed in rectangular piles within a HDPE lined cell (30 mil spec) or similar impervious surface. Each pile is typically designed to contain somewhere around 1000 cubic yards of soil. Typically the soil within each pile is mixed completely every 5 days to re-aerate the soil within the piles. Supplying oxygen to the bacteria is critical to move the process forward quickly.

If regular mixing of the soil is not accomplished using heavy equipment, the piles must be aerated using other mechanical methods. One method used often relies on forced air to push air into the soil. In this case, prior to placing soil on the liner, 4" corrugated plastic drain piping (commonly available at Lowe's, Home Depot, etc.) can be laid down on the bottom of the cell. Upon startup of treatment, this piping will be connected to reciprocating blowers to provide aeration to the soil pile. Individual sections of piping (typically 100' lengths) are connected so as to enable the piping to provide for one contiguous aeration line over the entire footprint of the cell. The piping is laid down in serpentine fashion across the cell so as to provide aeration at points across the footprint at no further than 3 feet from adjacent lines. Importantly, no aeration line should come any closer than three feet from the outside edge of the soil pile so as to prevent short circuiting of aeration. The line exiting the pile to the blower will, likewise, stop three feet from the projected edge of the pile.

At this point the drain line will be connected to a solid 2" PVC line via a reducing coupling.

The PVC line will run from the aeration piping to a reciprocating blower. The BER treated soil is placed over the aeration piping and base liner in a three foot lift with a track hoe. Once the layer is complete, a second layer of aeration piping will be strung as before across the soil layer. Also, as before, a solid PVC line will be attached to the aeration piping for ultimate connection to the blower. Another three feet of BER treated soil is placed over this piping. Additional layers can be placed upon the now six foot high pile if desired by repeating the aeration piping strategy.

Typically, a 100 CFM reciprocating blower (Rotron or Fuji) is required for each 500 cubic yards of soil treatment. The blowers can be used to blow air into the pile (preferred for winter conditions for heat purposes) or to pull air through the pile from the vacuum side of the blower. If the vacuum side of the blower is utilized (to pull air into the pile under vacuum) a knock out drum must be placed between the biopile and the blower to remove water that is pulled out of the pile. A sump pump within the knock out drum is utilized to return water to the biopile.

Once biopiles are complete they are typically covered with black HDPE sheets. The cover sheets are usually kept in place with rope. The edges are often covered with soil or other materials to keep wind from blowing them off of the piles. Exhaust holes are cut into the HPDE at selected places to mitigate the potential for creating a problem with excess air blowing into the system from the blowers and to provide places for boring test holes.

BIOLOGICAL DEGRADATION PRODUCTS

As previously presented, the end-products of biological degradation are carbon dioxide, nitrogen gas and water. None of these end-products will interfere with the bioremediation process. The soil is sufficiently buffered by the added nutrients to handle the amounts of carbon dioxide produced.

AIR EMISSIONS

Studies of air quality within an indoor soil treatment facility substantiated that volatile organic compound emissions are negligible as would have been expected. The two liquid sprays applied to the soil (nutrients and bacterial inoculum) serve to minimize volatilization. Water sprays are an effective VOC and dust control measure as recognized by the U.S.E.P.A.. Subsequently, the soils are placed in biopiles and covered with plastic serve to further minimize the loss of any volatiles. More importantly, volatiles are the most readily degraded compounds and are generally removed within 3 days after treatment with an average DRE of >98%.

An independent air monitoring study was performed on an indoor facility. The dimensions of the building are 160 feet wide by 400 feet long and 25 feet high. The soil receiving and BER processing areas are at one end and the side of the building with a footprint of about 25 feet by 80 feet. The remainder of the building is used for wind row treatment. The facility contained 5200 tons of gasoline and diesel contaminated soil that was already processed and standing in wind rows.

Additionally, approximately 700 tons of gasoline contaminated soil(average concentration of 3400 mg/kg) were stockpiled in the building and were being treated by the BER process during air monitoring. NIOSH Methods 1500 and 1501 were used for determining total hydrocarbons and aromatic hydrocarbons, respectively. Six air samples were taken. Three were in the immediate area of the soil processing area and three were from the area of the building holding the previously treated soils. Specifically, one sample was collected from inside the soil screen. The air samples are identified below.

Sample Number	Identification
1	Incoming soil truck unloading area
2	Inside soil shredder
3	Treated soil area next to processing area
4	Center of building
5	End of building most distant from processing area
6	Over incoming stockpiled soil pile

The results of the air monitoring were as follows.

Sample Number	Sample Time(min)	Sample Vol(L)	Air Concentration (mg/m ³)*				
			Benz	Tol	Eth Benz	Xyl	Tot. VOCs
1	310	15.2	0.2	0.8	0.3	2.6	33.4
2	293	14.4	2.5	9.4	3.0	30.5	421.2
3	290	14.6	0.2	1.2	0.5	3.9	42.1
4	279	14.3	0.2	0.8	0.3	2.4	29.2
5	254	13.0	0.2	1.0	0.3	3.1	36.4
6	249	12.4	0.3	1.4	0.6	4.4	48.6
ACGIH TWAs (mg/m ³)			32	188	434	434	

*ppm = (mg/m³) (24.45)/gram molecular weight of compound

TESTING

In addition to testing of the soil for nutrients prior to the start of the project, weekly testing for ammonia, nitrate and phosphate should be conducted to assure that nutrients are present in sufficient quantity. A test for pH should also be conducted prior to treatment and weekly thereafter to assure that carbon dioxide generation is not reducing pH to unacceptable levels.

Moisture levels are not typically a problem with proper application of the additives. However, the soil should not be allowed to become dry. Typically, a moisture level exceeding 16% is sufficient.

Regular testing for the reduction of target contaminants is the ultimate tool for assuring proper biotreatment.

Test kits can be obtained from a number of vendors for nutrient and pH. Chemetrics (800-356-3072) test kits are the ones most used by Innovative Remediation Technologies, Inc. for field testing.