

6.0 IN-SITU BIODEGRADATION

6.1 Process Description

In-situ biodegradation is the term for biological treatment processes that are performed in place and therefore do not require excavation and removal of the contaminated soil. Biodegradation of contaminants in soils is most often accomplished through bioventing, which employs subsurface addition of oxygen through air injection or soil gas extraction to promote the biodegradation of contaminants. Other *in-situ* bioremediation approaches include the infiltration of nutrients, electron acceptors (such as oxygen), and microorganisms to enhance the microbial activity and remediation of contaminants.

The main purpose of *in-situ* treatment is to stimulate the natural microbiological activity of soil to decompose organic constituents into carbon dioxide and water. Systems that work to enhance this natural biological activity typically use injection wells to provide an oxygen source (such as air, pure oxygen, or hydrogen peroxide) to stimulate aerobic degradation. In bioventing systems, oxygen is added to the subsurface through air injection wells within the contaminated soil or through vapor extraction wells at the perimeter of the contaminated zone. Nutrients may also be needed to support the growth of waste-consuming microorganisms. In some cases, microorganisms that have the ability to metabolize specific contaminants of interest may be added to the soil.

During *in-situ* biotreatment, biodegradation is actually only one of several competing mechanisms. The contaminants may also be leached,

volatilized, undergo chemical degradation, or be adsorbed onto the soil particles. The overall removal achieved by *in-situ* biotreatment processes represents the combined impact of all of these mechanisms. Field studies have shown that volatilization may account for the majority of VOCs that are removed (Dupont, 1993; HWC, 1993; Downey et al., 1994; van Eyk, 1994). Recent bioventing studies, however, have shown that volatilization can be minimized by optimizing the air flow rate so that volatilization accounts for less than 20% of the total hydrocarbon removal for these systems (Miller et al., 1991; Dupont, 1993; Downey et al., 1995). In addition, the vent gas can be recycled to further increase the fraction of contaminants biodegraded (HWC, 1993).

Like all biotreatment processes, *in-situ* treatment is not applicable for the remediation of non-biodegradable contaminants such as heavy metals and other inorganic compounds. Some halogenated organic wastes also are not amenable to biotreatment or may require substrates to biodegrade these contaminants. Test data from 137 sites have shown that bioventing has almost universal application for remediating hydrocarbon-contaminated soils, including gasoline, JP-4, diesel fuel, heating oils, and waste oils (AFCEE, 1994).

In many instances, sites are remediated initially using SVE to remove the more volatile constituents, and then the air flow rate is decreased and bioventing is used to biodegrade the remaining constituents.

Figure 6-1 shows a general schematic of an *in-situ* biodegradation

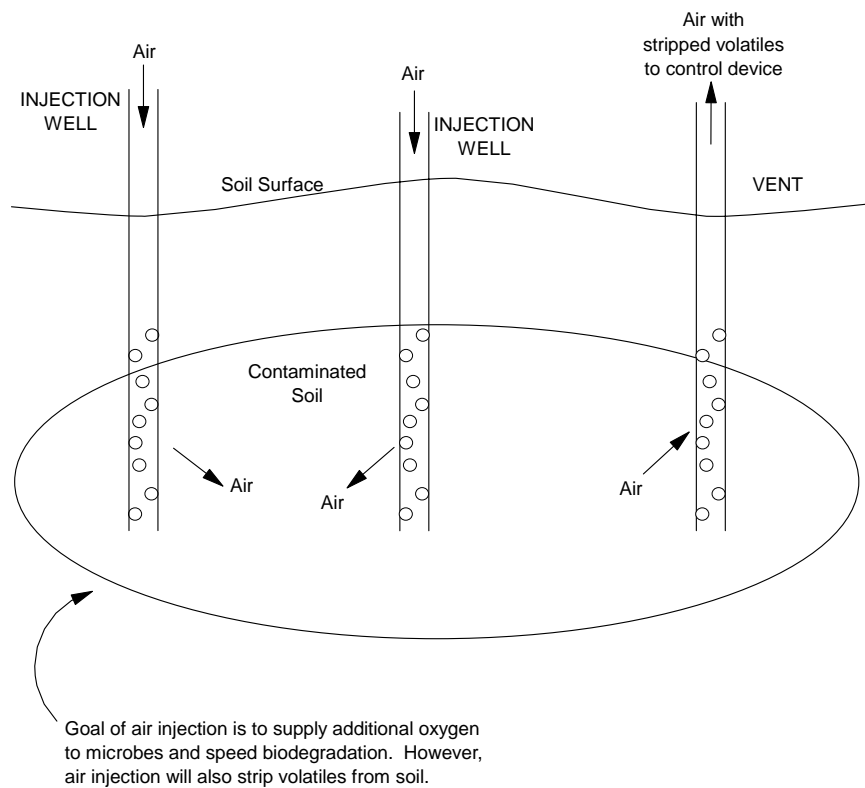


Figure 6-1. Flow Diagram for Off-Gas Treatment System For In-Situ Biodegradation

process. Air injection wells are installed within the zone of contamination to provide oxygen to stimulate the natural microbiological activity of the soils. An extraction or vent well can alternatively be used to provide oxygen to the subsurface, but this configuration may require off-gas treatment.

The primary factor affecting the volatilization of contaminants is the rate of air flow through the subsurface. The lower air flows used in bioventing, relative to soil vapor extraction systems, enhance biodegradation while minimizing volatilization. Other site factors, such as the temperature and soil moisture, can significantly affect the biodegradation rate for a site. As a result, competing mechanisms such as volatilization may predominate.

For an *in-situ* biotreatment process, the time required to treat the contaminated soil will vary greatly depending on a number of factors including the:

- Physical and chemical properties of the soil matrix;
- Physical and chemical properties of the contaminant;
- Initial concentration of the contaminant in the soil; and
- Biodegradability of the contaminants (i.e., biodegradation rate constants).

Hydrocarbon degradation rates have been measured from 300 to 7300 mg/kg TPH per year at numerous bioventing sites (Fredrickson, 1993; HWC, 1993). One site showed 99.5% removal as measured by soil TPH concentrations after 9 months of soil

vapor extraction and 14 months of bioventing treatment. The average and maximum initial TPH concentrations were <1000 mg/kg and 15,000 mg/kg, respectively. Biodegradation accounted for 44% of the total TPH removal.

The primary advantages of *in-situ* treatment, especially bioventing, are simplicity and low-cost. The equipment and operating costs for this type of treatment are very low compared to other technologies. The mechanical equipment required is simply a blower to inject or extract air.

The primary disadvantages of *in-situ* treatment are that only certain compounds are amenable to degradation, the removal efficiency may vary across a site, and the treatment may be relatively slow.

6.2 Identification of Air Emission Points

The specific point source of air emissions from bioventing systems is the off-gas collected by the extraction system. These vapors typically are collected through an extraction system and released through a short stack. Because the flow rate of bioventing systems is low and much of the contaminants are biodegraded in the subsurface, the off-gas from these systems often does not require treatment.

In some *in-situ* bioremediation systems, air injection wells are used to supply oxygen and no gas extraction system is employed. In such systems, area-wide emissions can occur, but the flow rates are typically low enough that emissions at the surface are thought to be minimal.

6.3 Typical Air Emission Species of Concern

Typical emissions from *in-situ* biotreatment process are a result of the volatilization of VOCs in the soil. The primary air emission species of concern are the specific volatile contaminants present in the soil. The air emissions may be biased towards the lighter molecular weight VOCs that make up the contamination. In addition, products of partial biodegradation are possible.

6.4 Summary of Air Emissions Data

Although *in-situ* biodegradation has been used to remediate numerous sites contaminated with petroleum hydrocarbons, few data on air emissions are available in the literature. Most bioventing studies have measured the concentration of contaminants in the system off-gas to estimate the fraction of total petroleum hydrocarbons volatilized versus bioremediated. As previously mentioned, sites may first be remediated using SVE to remove the more volatile constituents followed by bioventing to biodegrade the remaining constituents. Depending on the type and volatility of the contaminant, biodegradation can contribute from 50% to 90% to the total removal of petroleum hydrocarbons. Table 6-1 presents a summary of these data.

Source emission rates were determined at two sites, as shown in Table 6-2. Although the volatilization was in the range of 20 to 30 lb/day, the contribution of volatilization to the total removal was only 10% to 20%. To achieve this ratio of biodegradation to volatilization and minimize

air emissions, the bioventing system usually must be optimized.

The Hill AFB site is a good example of the difference in operating SVE systems versus bioventing systems and the amount of volatilization that can occur. Initially, the site was remediated by SVE and the volatilization and biodegradation rates were 200-400 lb/day and 70 lb/day, respectively. After 9 months of operation, the operating scheme was modified for bioventing. The bioventing volatilization and biodegradation rates were 20 lb/day and 100 lb/day, respectively.

Flux testing was conducted at five sites utilizing bioventing systems to measure the potential surface emissions during remediation. These results are summarized in Table 6-3. The maximum surface emission observed during the study was 2.5 mg/day/m². Rates of biodegradation are typically 100 times greater than the rates of volatilization observed at these sites (AFCEE, 1994).

6.5 Identification of Applicable Control Technologies

As the vapors are removed from the soil, they are either discharged to the atmosphere or treated to reduce air emissions. Bioventing utilizes low air flow rates to provide only enough oxygen to sustain biological activity, so off-gas treatment is rarely needed. Off-gas treatment is most likely to be needed at sites contaminated with VOCs that have vapor pressures greater than 1 atm because they will be more likely to volatilize rather than biodegrade (Cookson, 1995).

Table 6-1**Summary of Removal Rates for Bioventing Systems**

Site	Contaminant	Initial Soil Concentration	Removal Due to Volatilization	Removal Due to Biodegradation	Notes	Ref.
Burlington Northern RR, NE	No. 2 diesel fuel	20,000 to 50,000 mg/kg TRPH	<10%	>90%	2-yr bioventing test; Overall TRPH reduction: 55-60%	Downey et al., 1995
Eglin AFB, FL	gasoline	1200 mg/kg TRPH 500 mg/kg BTEX	35%	65%	Biodegradation exceeded volatilization as main removal mechanism after 30 days.	Downey et al., 1994
Retail gas station	gasoline	100 to 20,000 mg/kg BTEX 100 to 57,000 mg/kg mineral oil	800 kg hydrocarbons (1,764 lb hydrocarbons)	572 kg hydrocarbons (1,261 lb hydrocarbons)	Initially performed SVE; reduced air flow after week 67 for bioventing; 2 years of operation	van Eyk, 1994
Tyndall AFB, FL	jet fuel	NA	26 kg HC (45%) (57 lb HC)	32 kg HC (55%) (71 lb HC)	7-mo. test; Under optimal air-flow conditions, 82% HC removal by biodegradation (18% by volatilization) was achievable	Miller et al., 1991
Hill AFB, UT	JP-4	max. 15,000 mg/kg TPH avg. >1000 mg/kg TPH	53,600 kg (56%) (118,200 lb)	42,100 kg (44%) (92,900 lb)	Total removal: SVE for 9 mo. and bioventing for 14 mo. 99.5% overall contaminant removal	Dupont, 1993

Table 6-2

Summary of Source Emission Rates for Bioventing Systems

Site	Emission Rates	Total Emissions	Notes	Reference
Burlington Northern Railroad, NE	0.3 kg/day BTEX (0.7 lb/day BTEX) 14.7 kg/day diesel (32 lb/day diesel)	10,700 kg (23,600 lb) over 2 years	Equivalent to 600 mg/kg TRPH concentration reduction; <10% of removal by volatilization	Downey et al., 1995
Hill AFB, UT	9 kg/day (20 lb/day)	53,600 kg (118,200 lb) over 2 years (includes 9- month SVE test)	Biodegradation rate of 45 kg/day (100 lb/day); <20% of removal by volatilization (during bioventing test)	Dupont, 1993

Table 6-3

Summary of Surface Emissions at Bioventing Sites

Base	Site Type	Air Injection Rate, scmm (scfm)	TVH Flux Estimate (g/day)	Initial Soil Gas TVH (ppmv)
Plattsburg AFB, NY	Fire training pit	0.4 (13)	200	8400
Beale AFB, CA	Fire training pit	0.8 (30)	70	4800
Bolling AFB, D.C.	Diesel fuel spill	0.6 (20)	200	860
Fairchild AFB, WA	JP-4 fuel spill	0.4 (15)	150	29000
McClellan AFB, CA	Diesel fuel spill	1.4 (50)	30	380

Source: AFCEE, 1994

TVH = Total volatile hydrocarbons

AFB = Air Force Base

Although most bioventing systems do not contain VOC control systems, the most viable options when controls are necessary are similar to those for soil vapor extraction systems. These options include:

- Activated carbon;
- Catalytic oxidation; and
- Internal combustion engine.

Removal efficiencies of 95% to 99% should be theoretically achievable with any of these control options. A final option are biofilters which capture VOCs on soil beds and biodegrade the contaminants.

6.6 Costs for Remediation

Costs to perform *in-situ* bioremediation are low. The major capital investments are the blower and the treatment wells. Operating requirements are minimal and consist mainly of electricity and routine maintenance. The total costs for bioventing are in the range of \$10 to \$60 per cubic yard (AFCEE, 1994). The unit cost for bioventing is typically lower than SVE because off-gas treatment is not needed (Cookson, 1995). Unit costs are much lower than for low temperature thermal desorption and excavation/landfarming treatment processes (HWC, 1993; AFCEE, 1994).

The cost of a full-scale bioventing system for the remediation of 5,000 cubic yards of soil with an average concentration of 3,000 mg/kg of JP-4 would be \$90,300. This estimate includes pilot testing and 2 years of remediation (AFCEE, 1994).

6.7 Costs for Emissions Controls

Typically, emission controls are not required for bioventing systems. When controls are required, the cost is likely small,

on the order of \$20,000 to \$60,000. However, this cost can be a significant portion of the total remediation cost for bioventing systems.

6.8 Equations and Models for Estimating VOC Emissions

Vapor transport and biodegradation in contaminated soil are complex and competing processes. No practical, accurate theoretical models for predicting emissions or recovery rates are known to exist for bioventing systems. The pressure gradient (and related flow rate) and the biodegradation rate are the dominant factors in determining the mass rate of vapors.

Using data from pilot or full-scale tests at the site, air emissions can be estimated from the following mass balance equation (Eklund, et al., 1993):

$$ER = C_g (Q/60) 10^{-6}$$

where:

ER = Emission rate for contaminant of interest (g/sec);

C_g = Concentration of the contaminant in the soil gas ($\mu\text{g}/\text{m}^3$);

Q = Exhaust gas flow rate (m^3/min);

1/60 = Conversion factor (min/sec); and

10^{-6} = Conversion factor (g/ μg).

This equation does not address surface emissions.

If the extraction rate is not available from pilot tests, it can be estimated from the following:

$$Q = (1.0/1440) S_v E_a$$

where:

1.0 = Estimated flow rate for maximum biodegradation and minimum volatilization (pore volume/day);

1/1440 = Conversion factor (day/min);

S_v = Volume of soil (m^3); and

E_a = Air-filled porosity (fraction).

Bioventing systems typically operate at flow rates that are equivalent to 0.25 to 2.0 pore volumes per day. A flow rate of 1.0 pore volumes per day is thought to maximize the amount of biodegradation and minimize the amount of volatilization (Eklund, et al., 1993). Typically, flow rates for bioventing systems are between 10 and 50 acfm (Dupont, 1993).

Field data, such as field measurements from pilot tests, provide the most accurate values for the contaminant concentration. If field data are not available, a very conservative estimate can be made by assuming that the soil gas is saturated. The maximum vapor concentration is its equilibrium or saturated vapor concentration:

$$C_g = \frac{P_{vap} MW}{R T} 10^9$$

where:

P_{vap} = Pure contaminant vapor pressure at the soil temperature (mm Hg);

MW = Molecular weight of contaminant (g/gmol);

R = Gas constant (62.4 L-mmHg/gmol-°K);

T = Absolute temperature of soil (°K); and

10^9 = Conversion factor ($\mu g\text{-L/g-m}^3$).

This equation will overpredict the long-term average value since the soil gas concentration tends to drop exponentially over time (Downey et al., 1994). This calculation also does not account for biodegradation of contaminants, which is the primary removal mechanism in bioventing processes.

6.9 Case Study

No suitable case study was found for the *in-situ* bioremediation of soils contaminated with petroleum hydrocarbons.

6.10 References

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