Bioremediation- a green technology for environmental clean-up

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Abstract

Global population is rising at an alarming rate, leading to huge scale anthropogenic pollution of air, water and soil. According the World Health Organization (WHO), around 7 million people are killed each year from the air they breathe. According to the EPA, Bioremediation is a "treatment that uses naturally occurring organisms to break down hazardous substances into less toxic or non-toxic substances." This technology deploys microorganisms and plants to acquire, detoxify, degrade or remove toxic environmental contaminants (organic chemicals, heavy metals, oil and inorganic pollutants), even when they are present in low concentration. Microorganisms play a pivotal role in bioremediation process in nature by degrading complex human, animal, and plant wastes so that life can continue from one generation to the next. Bioremediation can be done either - *in situ* i.e. at the site of the contamination itself, or *ex situ* i.e. away from the site. There are three categories of bioremediation techniques to eliminate contaminants from environment: *in situ* land treatment for soil and groundwater; biofiltration of the air; and bioreactors, predominantly for water treatment.

Keywords: *Pollution, Contaminants, Bioremediation, Detoxification, Microorganisms*

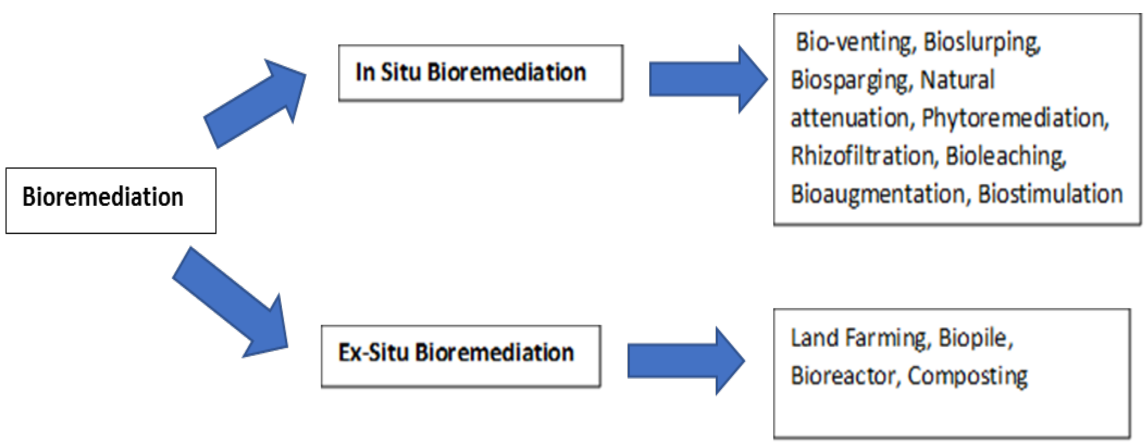
1. Introduction

Bioremediation is the process of remediating environment from waste pollution by using Bio-organisms. According to the EPA, Bioremediation is a "treatment that uses naturally occurring organisms to break down hazardous substances into less-toxic or non-toxic substances." Environmental pollution is increasing due to various reasons. So there is an urgent need to search for new eco-friendly, low-cost, and more efficient environmental clean-up techniques. Ability of microorganisms or plants to accumulate, detoxify, degrade, or remove environmental contaminants play a crucial role in bioremediation [1]. It is based on the ability of a microorganism as well as plants to degrade the hydrocarbons and many other toxic compounds into components that can easily be taken up by other microorganisms and plants as a nutrient source or can be safely returned to the environment. Those degraded organic components are converted into water, CO_2 and other inorganic compounds. To help the microorganisms to grow and degrade the pollutants at a rapid rate, environmental parameters should be optimum [2]. However, certain limitations are reported in this technology. Chlorinated hydrocarbons or other high aromatic hydrocarbons are almost resistant to microbial degradation or degraded at a slow pace [3]. Most of the techniques in bioremediation are aerobic in nature, but anaerobic processes also used to help degrade pollutants in oxygen deficit areas [4].

2. Classes of bioremediation strategies:

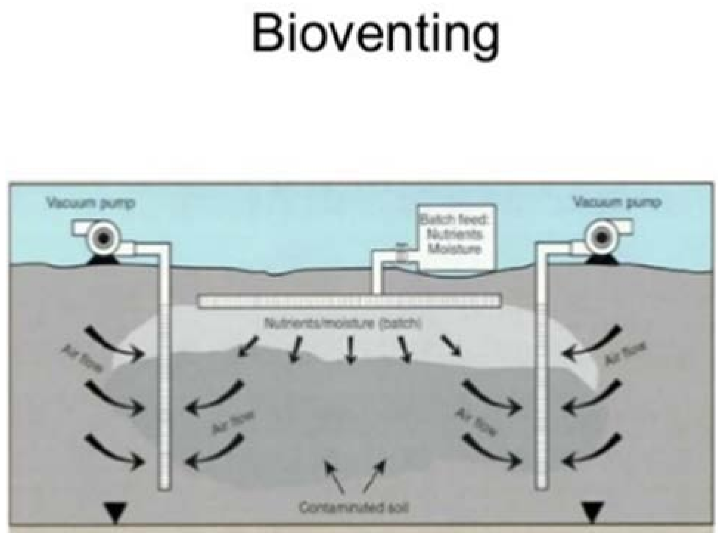
(i) ***In- situ* Bioremediation -** It is the process where contaminated waste is treated right at its point of origin. This method is cost effective and causes less disturbance to the surrounding area. It is mainly used for soil contamination due to oil spills. *In-situ* Bioremediation is limited up to 30-60 cm depth in soil up to which microorganisms can help degrade pollutants [3].

***(ii) Ex-situ* bioremediation** – It is the process where treatment occurs after the contaminated waste has been removed to a treatment area.

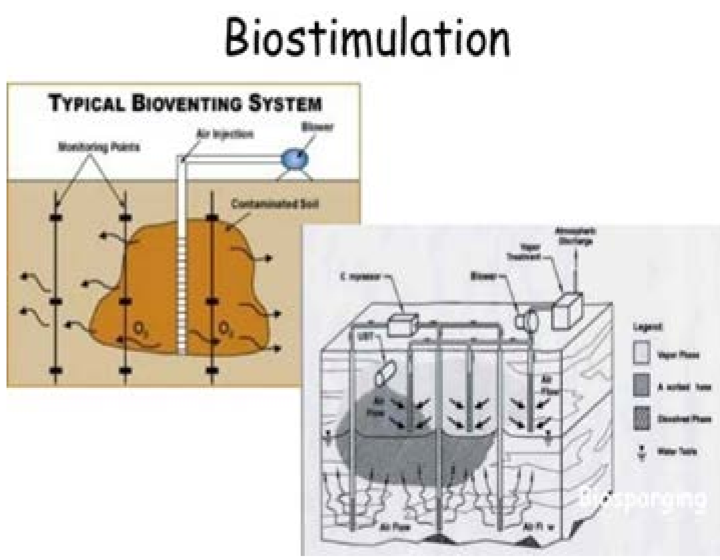


2.1 Types of *In-situ* Bioremediation –

(i) Bioventing – It is the process where oxygen venting takes place through soil to stimulate the growth of microorganisms present in the soil. Adsorbed fuel residuals are biodegraded. Volatile compounds are also biodegraded as vapors move slowly through biologically active soil. Effective bioremediation of petroleum contaminated soil has been proved by many researcher using bioventing. [5,6]



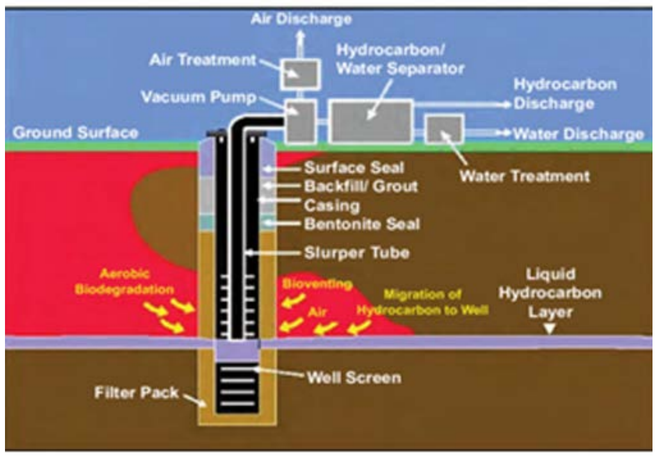
(ii) Biostimulation – It is the process where specific nutrients and electron acceptors, such as phosphorus, nitrogen, oxygen, or carbon (e.g. in the form of molasses) are injected at the site to stimulate indigenous microbial activities. [7]



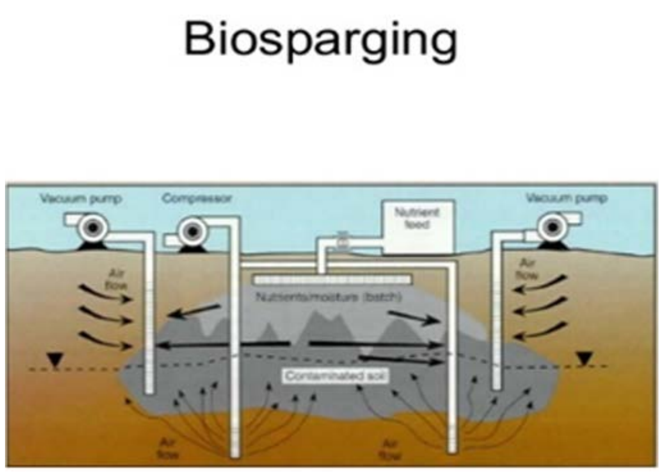
(iii) Bioattenuation – It is also known as natural attenuation, which eradicates pollutants from environment. It is carried out aerobically and anaerobically or with the help of plant and animal, physical phenomena like advection, dispersion, dilution, diffusion, volatilization, sorption/desorption, and chemical reactions like ion exchange, complexation, abiotic transformation[8].

(iv) Bioaugmentation - Bioaugmentation is the process of addition of pollutant degrading natural or exotic or engineered microorganisms to augment the biodegradative capacity of indigenous microbial populations on the contaminated area.

(v) Bioslurping – It is a technique where vacuum-enhanced dewatering technology is used to remediate hydrocarbon contaminated sites, mainly used in petroleum hydrocarbon contaminated soils. It is also applicable at sites with a deep ground water table (>30ft.) [9].

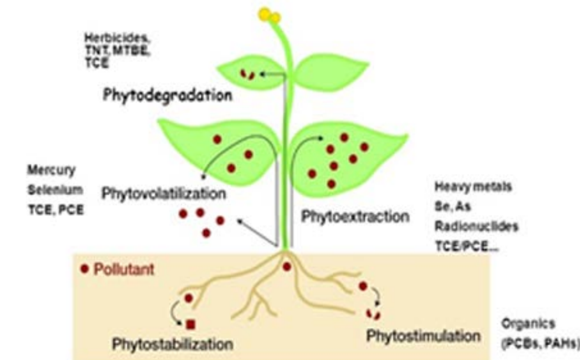


(vi) Biosparging – It is a technology that uses indigenous microorganisms to biodegrade organic constituents in the saturated zone. Here air (or oxygen) and nutrients are injected into the saturated zone to increase the biological activity of the indigenous microorganisms.



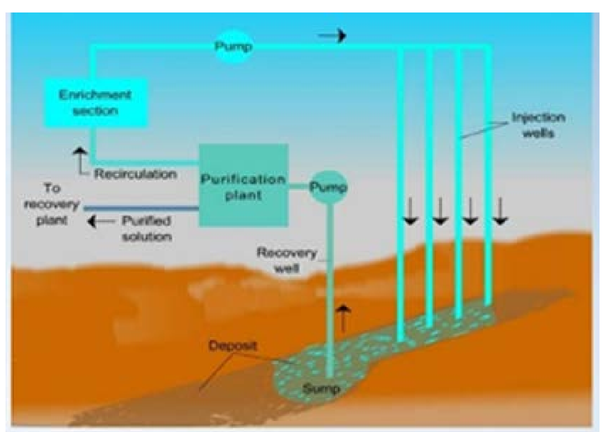
(vii) Phytoremediation – It is the direct use of green plants for removal, degradation, or containment of contaminants in soils, sludges, sediments, surface water and groundwater. Plants are unique organisms equipped with remarkable metabolic and absorption capabilities, as well as transport systems that can take up nutrients or contaminants selectively from soil or water. [10]

(viii) Rhizofiltration – It is the process of using hydroponically cultivated plant roots to remediate contaminated water through absorption, concentration, and precipitation of pollutants. It is a type of phyto-extraction where using aquatic-tolerant plants or aquatic vegetation to accumulate radionuclides primarily in the root system.



Nonbiological remediation technologies and bio/phytoremediation are not mutually exclusive.

(ix) Bioleaching – Also known as microbial ore leaching, is a process to extract metals from their ores using microorganisms which feed on nutrients in the minerals, causing the metal to separate from its ore.

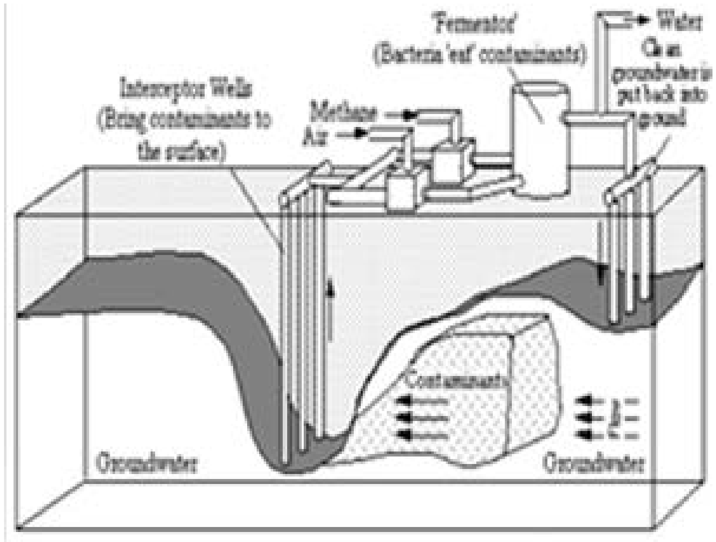


2.2 Types of *Ex-situ* Bioremediation –

(i) Land Farming – It is a bioremediation treatment process that is performed in the upper soil zone or in bio treatment cells. The soil is turned over regularly allowing air to mix with the excavated soil so that microorganisms present in the soil can efficiently break down the contaminants in soil [11-15].

(ii) Biopile (biocells, bioheaps, biomounds, and compost piles) - Here piles of soil are placed over top of a vacuum pump which pulls air through the pile of soil to allow oxygen to get thought the soil through aeration process to the micoorganisms. Microbial activity results in the breakdown of the petroleum constituents in the soil. Biopiles are aerated most often by forcing air to move by injection or extraction through slotted or perforated piping placed throughout the pile [16].

(iii) Bioreactor – It is a vessel like container where biological degradation of contaminants is controlled. Its function depends on contaminated soil or sludge or water, oxygen transfer and mixing. There are two types of soil bioreactors – Dry bioreactors and slurry bioreactors. Bioreactors can also be designed to be operated aerobically as well as anaerobically.



(iv) Composting - Composting is an aerobic method of decomposing organic solid wastes thereby used to recycle organic materials. In this process organic material is decomposed into a humus-like material, known as compost, which is a good fertilizer for plants. The most efficient composting occurs with an optimal carbon: nitrogen ratio of about 25:1 [17].

3. Factors for an effective microbial bioremediation: [18-25]

Factors	**Desired Conditions**
Microbial population	Suitable kinds of organisms that can biodegrade all of the contaminants
Oxygen	Enough to support aerobic biodegradation (about 2% oxygen in the gas phase or 0.4 mg/lt. in the soil water)
Water	Soil moisture should be from 50–70% of the water holding capacity of the soil
Nutrients	Nitrogen, phosphorus, sulfur, and other nutrients to support good microbial growth
Temperature	Appropriate temperatures for microbial growth (0–40˚C)
pH	Best range is from 6.5 to 7.5

4. Advantages and Disadvantages of Bioremediation [26]

ADVANTAGES	DISADVANTAGES
(i) Bioremediation is a natural process; it is widely accepted by the public as an effective way to remove hydrocarbon waste. The biodegraded compounds are harmless and can be incorporated in the environment (carbon dioxide, water, and biomass.)	(i) Bioremediation process is limited to compounds that are biodegradable. Not all hydrocarbon pollutants are biodegradable or susceptible to degradation by microorganisms. Example—chlorinated hydrocarbons
(ii) Bioremediation can be used for degrading wide variety of pollutants. This technique eliminates any future liability with the contaminants.	(ii) There are some concerns regarding the waste product that may be more toxic than that of the original product, thus harm the environment more.
(iii) Transferring contaminants may cause leaching and further contamination, bioremediation helps to degrade the pollutants on the site without causing additional hazard.	(iii) The growth of microorganisms for the bioremediation of the pollutant site is often very specific and demanding, the factors affecting the growth of microorganisms have to optimum for effective degradation by microbes.
(iv) Bioremediation method ensures that the waste from the biodegradation can be incorporated into the environment and does not have to be carried off-site for disposal.	(iv) Sites containing many different types of contaminants in various phases (solid, liquid, gas), which needs special treatment, or a combination of special microorganisms either native or genetically engineered.
(v) It is relatively inexpensive than other techniques used for clean-up of hazardous waste products.	(v) It is a time-consuming process and may need extra pre-treatment before they can be degraded by microorganisms (excavation, incineration). Which makes this process tedious.

5. Important microorganisms for bioremediation

5.1 For oil bioremediation [27-33]

Microorganisms	**Compounds**
Fusarium sp.	oil
Alcaligenes odorans, Bacillus subtilis, Corynebacterium propinquum, Pseudomonas aeruginosa	oil
Bacillus cereus A	diesel oil
Aspergillus niger, Candida glabrata, Candida krusei and Saccharomyces cerevisiae	crude oil
B. brevis, P. aeruginosa KH6, B. licheniformis and *B. sphaericus*	crude oil
Pseudomonas aeruginosa, P. putida, Arthobacter sp and Bacillus sp	diesel oil
Pseudomonas cepacia, Bacillus cereus, Bacillus coagulans, Citrobacter koseri and Serratia fi caria	diesel oil, crude oil

5.2 For utilizing heavy metals [34-44]

Microorganisms	**Compounds**
Saccharomyces cerevisiae	Heavy metals, *lead, mercury* and *nickel*
Cunninghamella elegans	Heavy metals
Pseudomonas fluorescens and *Pseudomonas aeruginosa*	*Fe* 2+, *Zn*2+, *Pb*2+, *Mn*2+ *and Cu*2
Lysinibacillus sphaericus CBAM5	*cobalt, copper, chromium and lead*
*Microbacterium profundi strain Shh49*T	*Fe*
Aspergillus versicolor, A. fumigatus, Paecilomyces sp., Paecilomyces sp., Terichoderma sp., Microsporum sp., Cladosporium sp.	*cadmium*
Geobacter spp.	*Fe (III), U (VI)*
Bacillus safensis (JX126862) strain (PB-5 and RSA-4)	*cadmium*

Pseudomonas aeruginosa, *Aeromonas* sp.	U, Cu, Ni, Cr
Aerococcus sp., *Rhodopseudomonas palustris*	Pb, Cr, Cd
Bacillus thuringiensis KUNi1	Ni

5.3 Microorganisms involved in bioremediation of dyes [45-52]

Microorganisms	**Compounds**
B. subtilis strain NAP1, NAP2, NAP4	oil-based based paints
Myrothecium roridum IM 6482	industrial dyes
Pycnoporus sanguineous, Phanerochaete chrysosporium and *Trametes trogii*	industrial dyes
Penicillium ochrochloron	industrial dyes
Micrococcus luteus, Listeria denitrifi cans and Nocardia atlantica	Textile Azo Dyes
Bacillus spp. ETL-2012, Pseudomonas aeruginosa, Bacillus pumilus HKG212	Textile Dye (Remazol Black B), Sulfonated di-azo dye Reactive Red HE8B, RNB dye
Exiguobacterium indicum, Exiguobacterium aurantiacums, Bacillus cereus and Acinetobacter baumanii	azo dyes effl uents
Bacillus fi rmus, Bacillus macerans, Staphylococcus aureus and Klebsiella oxytoca	vat dyes, Textile effl uents

5.4 Potential microbial agents for pesticide remediation [53-56]

Microorganisms	**Compounds**
Bacillus, Staphylococcus	Endosulfan
Enterobacter	Chlorpyrifos
Pseudomonas putida, Acinetobacter sp., Arthrobacter sp.	Ridomil MZ 68 MG, Fitoraz WP 76, Decis 2.5 EC, malation
Acenetobactor sp., Pseudomonas sp., Enterobacter sp. Photobacterium sp.	chlorpyrifos and methyl parathion

Conclusion

Bioremediation is a scientific technique that can be used to reduce or nullify the contaminants as well as pollutants in the surroundings though with certain limitations**.**

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