14 Microbial Clean-Up Strategy for Eating Garbage

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Abstract

Bioremediation is the deliberate use of biological mechanisms to clean up pollutants, viz. hydrocarbons, oil, heavy metal, pesticides and dyes, by letting the microbes eat and digest toxic contaminants and consequently transform them into gases, water and other less toxic components. The indispensable habit of using products made out of plastic has led to the pollution havoc in the present day. The physical and chemical degradation methods do not provide an eco-friendly solution to disposal of garbage. Here, the usage of microorganisms has emerged as a key alternative offering solution to the challenges of reifying environment-friendly garbage clean-up. The resiliency of microorganisms to survive even the harshest of environmental conditions and the extreme diversity in microbial communities which comprise as many as 10,000 distinct microbial species per gram of soil make them highly effective in bioremediation of almost all environmental pollutants. As such, bioremediation is a highly promising solution for the degradation, eradication, immobilization and detoxification of chemical and physical waste materials. In addition, the process is also cheaper in equipment and labour costs in comparison to the physical and chemical treatment solutions. So bioremediation has a great contributory role to play in solving many existing and future environmental problems.

Keywords

Bioremediation · Microorganisms · Environment · Pollutants

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14.1 Introduction

The expansion in urbanization, industrialization and population has rapidly increased the human contribution to environmental contamination in our recent century. Today the contamination is dangerous enough to potentially lead to extinction of rare and endangered species and also put our own existence in peril with the contamination of air, water and food sources. Existing chemical and physical treatment solutions for waste products lead to further contamination of environment because of the harmful residuals left after the treatment.

As such, the biotreatment of contaminated areas is increasingly finding leading applications in recent years. The traditional physical method of doing remediation is to dig up the contaminated soil and isolate and remove the areas covering the contaminated sites. These methods introduce risks during the excavation, handling and transportation of hazardous waste materials. Moreover, the cost of performing incineration, excavation, landfilling and storage makes these methods expensive and inefficient. Finding landfill sites for final disposal of contaminated waste materials is not trivial and requires several considerations to be made with security of individuals residing in neighbouring areas (Bollag and Bollag 1995).

Bioremediation offers an eco-friendly waste disposal alternative in order to solve the disadvantages of traditional waste disposal methods. Bioremediation is the method that relies on different microorganisms to degrade the pollutants into less poisonous types. Compared with conventional treatment, the main differentiating advantages of bioremediation are its relatively low cost and high efficiency with no additional nutrient requirement and minimal site disruption, thereby leading to greater public acceptance. However, the application of bioremediation is limited by the availability of microorganisms and also the presence of some chemicals with low water solubility and those which are not amenable to biodegradation (such as heavy metals, some chlorinated compounds, radionuclides).

The process of transforming natural assets accessible in the environment into types suitable for our usage is central to contemporary human activities. This method produces dangerous by products and therefore leads to the current issue of unnecessary air, water and land pollution. As such, any sustainable solution to the disposal of generated wastes in an environmentally safe way must conveniently integrate them back into the environment by reducing the concentration of harmful contaminants. Microorganisms (generally yeasts, bacteria or fungi) must be used. This is achieved by integrating the microorganisms or their products into the substrates to derive industrial products such as bioleaching (biomining), biodetergent, biotreatment of pulp, biotreatment of wastes (bioremediation), biofiltrations, aquaculture treatments, biotreatment of textiles, biocatalysts, biomass fuel production, biomonitoring and so on.

Microbes already play a significant role in safe disposal and reuse of garbage as the natural recycling of all living materials is performed by the microbes. All naturally produced materials are biodegradable. Microbes are nature's supreme waste dump. It is a testimony to their effectiveness that we, humans, have coerced them to clear up our natural messes for centuries. They have become invaluable and vital in discovering alternatives to several challenging human issues to guarantee the value of our surroundings. They had a beneficial impact on human and pet safety, DNA technology, economic safety and corporate and agricultural disposal methods. Microorganisms have been the catalyst in implementing feasible and cost-effective waste disposal solutions which otherwise would have been impossible via chemical or physical engineering methods.

Microorganisms have amazing metabolism and can develop easily in severe climate circumstances. This dietary adaptability of microorganisms to transform, alter and use poisonous pollutants to acquire power is utilized by bioremediation to biodegrade pollutants.

In contrast to naively gathering the pollutant and increasing the danger by transporting it, the method of bioremediation involves establishing a microbiological well to promote organized microbial growth to break down contaminants and convert damaging chemicals into less poisonous or non-toxic ionic and compound types. Bioremediators are these biological substances used to remediate contaminated locations. Therefore, the bioremediation method can be defined as the biotechnological method incorporating the implementation of microorganisms as bioremediators to remove many pollutant hazards. Typical primary bioremediators are bacteria, archaea and fungi, and their use is recommended to restore the initial natural environment and prevent further destruction (Vidali 2001; McKinney 1957).

14.1.1 Principles of Bioremediation

Bioremediation is the most efficient instrument for managing the polluted atmosphere, where organic waste is biodegraded to an innocuous state under regulated circumstances. Microorganisms, in fact, are able to destroy, degrade and even absorb damaging organic and nitrogen compounds (Jain and Bajpai 2012). Higher vegetation was also recorded to prevent such pollutants, mainly through the capacity to collect them in their bodies (Kumar et al. 2011). Bioremediation aims to encourage microorganisms to operate by providing optimum concentrations of oxygen and other chemicals necessary for their development to detoxify materials that are harmful to the atmosphere and human objects (Rathore 2017). Enzyme mediated all cellular responses. These relate to oxidoreductase, hydrolase, lyase, transferase, isomerase and ligase classes. Because of their non-specific and particular surface binding, many enzymes have extremely broad degradation ability. Bioremediation can also only be efficient if environmental circumstances permit microbial development; its implementation often includes manipulating environmental parameters to enable microbial development and degradation to continue at a quicker pace (Vidali 2001).

Bioremediation is based on natural attenuation, identified as natural procedures (mostly microbes but may also include fungi, algae and higher plants) in the environment that operate without human interference to decrease the quantity or toxicity of contaminants (Sharma 2011–2012).

Environmental biotechnology has been used to create effective solutions to solve difficult problems faced by humans in recent century. The steep advancement of molecular biology and biotechnology has allowed us to exploit the biological processes more efficiently to clean up polluted water and land areas through biological process. Biotechnological methods to handle garbage before or after it is carried into the surroundings are elements of biotechnological management techniques. Biotechnology can also be used industrially to develop goods and procedures that produce less cost, use less resources and require less power.

Recombinant DNA engineering has enhanced pollution reduction options and claims to further develop bioremediation (Vandevivere et al. 1998). Bioremediation utilizes real environment organisms, fungi and vegetation where the enzymes generated by these microbes target the contaminants and then transform these into non-toxic materials. To be efficient, environment conditions should promote microbial development (Mrozik et al. 2003). Bioremediation effectiveness relies on many variables, including the chemical type and intensity of pollutants, the physicochemical properties of the environment and their accessibility to microorganisms (El Fantroussi and Agathos 2005). Besides, microbes and pollutants do not distribute evenly in the surroundings. Many variables make monitoring and optimizing bioremediation procedures a complicated process.

Since this method is a challenging job, it includes three primary components – the environment, contaminants and microorganisms. Appropriate climate, humidity composition, pH, water availability and ion acceptors such as oxygen for aerobic microorganisms promote biological behaviour in the ecosystem (Fritsche and Hofrichter 2008).

14.1.2 Use of Microorganisms in Waste Management

Bacteria, fungi, algae and other microorganisms can be used for industrial waste treatment. Their use and efficiency relies on the sort of chemical pollution, environmental circumstances and microbial development supporting variables like resource accessibility and temperature, pH, humidity and availability of electron acceptors such as oxygen. These microorganisms are categorized as follows.

14.1.3 Use of Bacteria

Bacteria are the most used microorganism in any disposal scheme. They have different biochemical characteristics and metabolize most organic material in any industrial waste. Many microorganisms even eat exclusively on hydrocarbons (Yakimov et al. 2007). Biodegradation of hydrocarbons can happen under aerobic and anaerobic circumstances, as is the situation with *Pseudomonas* sp. and *Brevibacillus* sp. (Grishchenkov et al. 2000). Wiedemeier et al. (1995), however, indicate that anaerobic biodegradation may be much more essential. Among the hydrocarbon-degrading organisms isolated from the coastal environment (Floodgate

1984), the organisms corresponding to the ten species: *Bacillus*, *Corynebacterium*, *Staphylococcus*, *Streptococcus*, *Shigella, Alcaligens*, *Acinetobacter*, *Escherichia*, *Klebsiella* and *Enterobacter* were selected (Kafilzadeh et al. 2011) and *Bacillus* species was found to be the highest degrading organisms among all. Bacterial species capable of degrading organic hydrocarbons have been consistently extracted, primarily from land. These are generally Gram-negative bacteria, mostly belonging to the *Pseudomonas* genus. Biodegrading processes were also reported in the species *Mycobacterium*, *Corynebacterium*, *Aeromonas*, *Rhodococcus* and *Bacillus* (Mrozik et al. 2003). Although many bacteria can metabolize natural pollutants, one bacterium doesn't have the enzymatic capacity to deteriorate all or even most toxic chemicals in a polluted land. Mixed microbial populations have the most important biodegrading ability because more than one organism's genome data is crucial to degrade complicated mixtures of natural compounds in contaminated fields (Fritsche and Hofrichter 2005). Aerobic and anaerobic fungi can biotransform PCBs. Higher chlorinated PCBs are dehalogenated by anaerobic microorganisms, and lower chlorinated biphenyls are oxidized by aerobic bacteria (Seeger et al. 2001). Research on indigenous aerobic fungi has concentrated primarily on Gram-negative species of the species *Pseudomonas*, *Burkholderia*, *Ralstonia*, *Achromobacter*, *Sphingomonas* and *Comamonas*. However, several studies on PCB-degrading behaviour and gene identification of microbes involved in PCB degradation also suggested PCB-degrading ability of some Gram-positive species (genera *Rhodococcus*, *Janibacter*, *Bacillus*, *Paenibacillus and Microbacterium*) (Petric et al. 2007). Aerobic catabolic pathway for PCB degradation seems to be very similar for most of the bacteria and comprises four steps catalysed by the enzymes biphenyl dioxygenase (BphA), dihydrodiol dehydrogenase (BphB), 2, 3-dihydroxybihenyl dioxygenase (DHBD) (BphC) and hydrolase (BphD) (Taguchi et al. 2001).

Effective removal of pesticides by adding bacterium was noted earlier for many compounds, including atrazine (Struthers et al. 1998). Recent findings concerning pesticide-degrading bacteria embrace the chlorpyrifos-degrading bacterium *Providencia stuartii* isolated from agricultural soil (Surekha et al. 2008) and isolates *Bacillus*, *Staphylococcus* and *Stenotrophomonas* from cultivated and uncultivated soil able to degrade dichlorodiphenyltrichloroethane (DDT) (Kanade et al. 2012) (Table 14.1).

14.1.4 Fungi

In the waste management scheme, fungi that can metabolize several organic compounds may also be employed. Except under uncommon environmental circumstances, they dominate the bacteria. *Phanerochaete chrysosporium* fungi can degrade a wide variety of permanent or toxic environmental pollutants. Straws, sawdust or cobs are commonly used substrates. Fungi are most effective, particularly when the natural polymeric compounds break down, and are equipped with extracellular enzyme systems. They can also quickly colonize and enter substrates and transport and redistribute nutrients into their mycelium through their hyphal systems

Table 14.1 Examples of microorganisms involved in bioremediation

Contaminants	Microorganisms
Atrazine	*Pseudomonas* sp. (ADP)
2,4,6-Trinitrotoluene	*Methanococcus* sp.
Chlorpyrifos	*Enterobacter* sp.
Dibenzothiophene (DBT)	*Rhizobium meliloti*
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	*Acetobacterium paludosum*, *Clostridium acetobutylicum*
PAHs	*Pseudomonas* sp., *Pycnoporus sanguineus*, *Coriolus versicolor*, *Pleurotus ostreatus*, *Fomitopsis palustris*, *Daedalea elegans*
Phenanthrene, PAH	*Agrobacterium*, *Bacillus*, *Burkholderia*, *Pseudomonas* and *Sphingomonas*
Polychlorinated biphenyl (PCB)	*Rhodococcus erythropolis*, *Rhizobium* sp.
Polycyclic aromatic hydrocarbon (PAH)	Fungi

Source: Kang (2014)

(Matavuly and Molitoris 2009). Mycorrhiza is a symbiosis between a fungus and vascular crop roots. The fungus colonizes the roots of the host plant in a mycorrhizal association, both intracellularly such as in arbuscular mycorrhizal (AMF) mushrooms and extracellularly, for instance, in ectomycorrhizal fungi. They are also a key element in soil life and chemistry. Mycorrhizal biological remedial treatment is called mycorrhizal remediation (Khan, 2006). Fungi have significant degrading functions that affect the recycling of recalcitrant materials (e.g. lignin) and the disposal of environmentally hazardous waste (Fritsche and Hofrichter 2005).

14.1.5 Algae

Algae that use sunlight as an energy source may also be used to manage inorganic waste such as ammonia, carbon dioxide, magnesium, potassium, iron, calcium, sulphate, phosphate and sodium. Algae and bacteria can be used together for the same waste components. Organic waste components are metabolized into inorganic components by bacteria, which are then used by the algae.

Species of *Chlorella*, *Anabaena inaequalis*, *Westiellopsis prolifica*, *Stigeoclonium lenue* and *Synechococcus* withstand heavy metals. A number of species of *Chlorella*, *Anabaena* and marine algae have been employed in the suppression of heavy metals, but operational circumstances restrict their practical implementation (Dwivedi 2012). Metals are absorbed by adsorption of algae. Unicellular algae have recorded metal chelation. Biosorption of heavy metals by brown algae is known for a long period, including the extraction of heavy metals by a variety of cell wall elements like alginate and fucoidane of heavy metals. Most study has been conducted in this field on marine and land algae (Davis et al. 2003). It has been indicated that the microalga *S. incrassatulus* can be used to remove Cr(VI), Cd

(II) and Cu(II) in continuous cultures (Pena-Castro et al. 2004). Heavy metal bioremediation was also recorded for green algae, for instance, *C. sorokiniana* for Cr(III) removal (Akhtar et al. 2008).

14.1.6 Protozoa

Protozoa are the most basic types of microorganisms to be used in waste disposal processes. The protozoa may assist in the decrease of the population of useless bacteria instead of being the primary part of treatment system. They therefore help to produce a clear effluent. The protozoans are the primary grazer for degrading bio-pollutants, which affects the relation of the protozoa with degrading bacteria. In order to examine the impact of protozoan flagellate Heteromita in the biodegradation of benzene and methylbenzene, Mattison and Harayama (2015) have developed a model for the food chain. The study discovered that the degrading rates of benzene and methylbenzene were 8.5 times better in bacteria than before during the logarithmic increasing population of the flagella population. The protozoa infusors clearly can speed the biodegradation of heterogeneous materials such as PAH. For instance, the naphthalene degradation speed can be four times higher than before.

The protozoa process that accelerates the biodegradation of organic contaminants can be expected to include several feasible hypotheses, primarily six of which are:

1. Mineralisation of nutrients that increases nutrient turnover
2. Activation of bacteria that regulates the amount, destroys old cells and excretes an active ingredient
3. Selective grazing, which decreases resource and space competition and is therefore useful for the development of degrading bacteria
4. Physical disruption that can boost the level of oxygen and the degrading matter surface
5. Direct degradation that can excrete specific degradation enzymes
6. Sym-metabolism that provides bacteria with energy and carbon resources during degradation (Chen et al. 2007)

14.1.7 Factors of Bioremediation

The management and optimization of procedures of bioremediation have many complicated variables: the presence of a pollutant-degrading microbial population, the accessibility of contaminants and the environmental variables (type of soil, temperature, pH, the presence of oxygen or other electron acceptors and nutrients) (Table 14.2).

14.1.7.1 Biological Factors

The biotic variables influence organic degradation through the competition between microorganisms for restricted carbon supplies, antagonistic relationships or

Table 14.2 Showing factors of bioremediation

Factors of bioremediation	Condition required
Microorganisms	Aerobic or anaerobic
Natural biological processes of microorganism	Catabolism and anabolism
Environmental factors	Temperature, pH, oxygen content, electron acceptor/donor
Nutrients	Carbon, nitrogen, oxygen, etc.
Soil moisture	25–28% of water holding capacity
Type of soil	Low clay or silt content

protozoan predation of microorganisms. Contaminant degradation speed often depends on contaminant density and the quantity of "catalyst" available. In that regard, both the number of organisms able to metabolize contaminants and the quantity of enzymes created within each cell are represented as the "catalyst" amount (Madhavi and Mohini 2012). Expression of particular enzymes can boost or reduce contaminant degradation. The magnitude of the contaminant metabolism should also involve particular enzymes, and the contaminant's "affinity" to them as well as their accessibility is essential. The major biological factors are as follows: mutation, horizontal gene transfer, enzyme activity, interaction (competition, succession and predation), its own growth until critical biomass is reached, population size and composition (Boopathy 2000).

14.1.7.2 Environmental Factors

The metabolic characteristics of the microorganisms and physicochemical properties of the targeted contaminants determine possible interaction during the process. The actual effective interaction between the two, however, relies on the site's environmental conditions. Microorganism reproduction and activities are influenced by pH, heat, humidity, land composition, water solubility, nutrients, location features, redox ability and oxygen material, absence of qualified human capital in this sector and pollutant bioavailability (contaminant quantity, form, solubility, chemical composition and poisoning). These above variables determine kinetics of degradation (Adams et al. 2015). Biodegradation can happen under a wide pH range; however, in most marine and land environments, pH 6.5–8.5 is usually ideal for biodegradation. Moisture affects contaminant consumption frequency because it affects the type and quantity of soluble products, as well as the osmotic stress and pH of natural and freshwater environments (Cases and De Lorenzo 2005). Most environmental variables are discussed below.

14.1.7.3 Availability of Nutrients

Adding oxygen adjusts the vital nutritional equilibrium for microbial development, as well as affects biodegradation frequency and efficiency. Nutrient mixing, particularly by supplying vital proteins such as N and P, can enhance the biodegradation effectiveness by optimizing the C:N:P proportion. Microorganisms need several elements such as carbon, oxygen and phosphorus to sustain and maintain their microbial operations. Adding a suitable amount of nutrients is a good approach to increase the cellular function of microorganisms and consequently the biodegradation speed in harsh settings (Couto et al. 2014; Phulia et al. 2013). Aquatic biodegradation is similarly restricted by nutrient accessibility (Thayasi et al. 2011). Like other species' dietary requirements, oil-eating microbes also demand adequate nutrients for their growth and development (Macaulay 2015).

14.1.7.4 Temperature

Among the most significant physical variables to determine microorganism longevity is heat (Das and Chandran 2011). In harsh freezing settings such as the Arctic, oil degradation through normal produces is very low, putting more stress on the microbes to clear up accumulated petroleum. The under-zero temperature of the water is responsible for the suppression or even freezing of the full cytoplasm of transportation canals in microbial bodies, thereby making most inactive (Yang et al. 2009). Moreover, the degradation of different compounds requires different temperatures. Temperature also speeds or slows down bioremediation processes as microbial physiological characteristics are extremely influenced. Microbial activity speed rises with heat, reaching its highest amount at optimum heat. It abruptly declines with higher or lower heat and ultimately stops after approaching a particular heat.

14.1.7.5 Concentration of Oxygen

Some bacteria need oxygen to improve their biodegradation level. Other species however require no oxygen for biodegradation. Biological degradation occurs aerobically and anaerobically, as for most living organisms, air is necessary for survival. In most cases, the presence of oxygen could improve the metabolism of hydrocarbons (Macaulay 2015).

14.1.7.6 Moisture Content

To achieve their growth, microorganisms necessitate sufficient oxygen. Biodegradation inhibitors and the soil humidity content have the most negative impact.

14.1.7.7 pH

pH for a substance, defined mainly as acidity, basicity and alkalinity, has its own effect on metabolic activity as well as influences removal process. Soil pH measurement could show microbial growth potential (Enim 2013). Lower or higher pH values have shown less metabolic processes (Wang et al. 2011).

14.1.7.8 Site Characterization and Selection

Enough remediation work should be done in order to properly characterize the magnitude and extent of contamination before a bioremediation solution is proposed. The following factors should at least be covered in this job. The horizontal and vertical extent of contamination should be completely determined, the sites must be specified and the justification for choosing them should be listed and the techniques for sampling and analysis should be well described.

14.1.7.9 Metal Ions

In tiny quantities, metals are essential for bacteria and fungi, but they prevent the metabolic activity of cells in large quantities. Metal compounds can affect the degradation rate directly and indirectly.

14.1.7.10 Toxic Compounds

The decontamination by microorganisms if slowed down when the concentration of toxic contaminants is high. The toxicity level and processes depend on the particular toxicants, concentration and microorganisms being exposed. Some organic and inorganic substances can be poisonous to specific types of microorganisms (Madhavi and Mohini 2012).

14.1.7.11 Prospects for Increasing the Effectiveness of Bioremediation

The efficacy and variety of the microorganisms used in the method directly affect bioremediation. The variety of microorganism communities enables the overall use of bioremediation techniques to restore sites contaminated with various pollutants. As a result, better knowledge of the role of catabolic paths and microbial metabolic functions facilitates improving the efficiency of bioremediation procedures. The restricted supply of nutrients is another significant factor that affects the efficacy of bioremediation techniques. The addition of nutrients is known as biostimulation and is a strategy to improve the efficiency of microbial operations. The indigenous microbes reveal a rise in their activity when biostimulation is applied and can resist the degrading impacts of extremely concentrated pollutants. However, it is also suggested that nutrients not be overused (Wang et al. 2012). The promotion of microbial population growth and diversity is an orthogonal strategy to increase the accessibility of nutrients. This strategy is known as “bioaugmentation” and benefits from the synergy among the various metabolic microbial procedures (Silva-Castro et al. 2012; Bhattacharya et al. 2015).

14.1.8 Bioremediation Strategies

14.1.8.1 Ex Situ Bioremediation

The pollutants are excavated and transferred to another site for processing in this method. The use of this method depends, for instance, on the circumstances at the contaminated site: is the pollutant deeply contaminating the soil, is it extremely concentrated, is the pollution costly to treat on the ground (Philp and Atlas 2005).

14.1.8.2 Biopile

This method excavates the pollutant over the floor into stacks and then adds nutrients to boost the development and activity of microbials. Bioremediation is also improved by aeration that increases the microbial activity. This is an economical method for supporting efficient biodegradation when sufficient amounts of nutrients and aerating exist (Whelan et al. 2015). It also avoids the gassing into the environment of low molecular weight (LMW) pollutants. The technology can be used also in cold areas (Whelan et al. 2015; Dias et al. 2015; Gomez and Sartaj 2014).

14.1.8.3 Windrows

The piled polluting soil is regularly shifted to improve bioremediation in this method. This ensures uniformity of the microbial population, pollutant concentration, water and aeration and nutrient accessibility throughout the polluted site (Barr 2002). Windrow is more efficient in the removal of hydrocarbons compared to biopiles. It is used, however, until the soil type is more friable (Coulon et al. 2010). The drawback is that greenhouse gases are released when anaerobic areas begin to grow in stacked areas (Hobson et al. 2005).

14.1.8.4 Bioreactor

This vessel is designed to provide microbial biological responses against contaminants that are fed as slurry. This technique offers closer control over parameters such as temperature, pH and aeration other than ex situ procedures, thereby efficiently improving biological responses to decrease bioremediation time. Furthermore, bioreactor also can be used to treat volatile organic compound contamination such as benzene.

14.1.8.5 Land Farming

The method can be considered either as ex situ or in situ depending on the pollutant concentration at the treatment location and is a low-price and extremely economical method. The treatment is in situ if excavated soil is processed at the same site; otherwise it is ex situ. If it is in situ and if the contaminant does not reach the depths of the soil, then it is not necessary to excavate polluted soil (Nikolopoulou et al. 2013). The groundwater pollute is stored after excavation over the floor to enable indigenous microbes to aerobically biodegrade (Philp and Atlas 2005; Paudyn et al. 2008; Volpe et al. 2012; Silva-Castro et al. 2015). Tillage and irrigation are the main activities of agriculture. Tilling enhances the accessibility of aeration and nutrients. This stimulates the operations and increases bioremediation of autochthonous microorganisms.

14.1.8.6 In Situ Bioremediation Technique

The polluted soil is not dug in this method; instead, contaminants are handled at the site with very less soil distortion. It is a cost-effective method because of reduced excavation costs. However, some construction and on-site machinery costs are involved for its efficient implementation. It is applied for the treatment of chlorinated solvents, dyes, heavy metals and polluted hydrocarbon locations (Folch et al. 2013; Kim et al. 2014; Frascari et al. 2015).

14.1.8.7 Bioventing

Bioventure takes place through regulated manipulation of the airflow to deliver oxygen to the unsaturated (vadosic) area and to boost indigenous microbial processes. In order to enhance bioremediation, nutrients and humidity are introduced (Philp and Atlas 2005). It is usually supplemented by other on-site techniques of bioremediation. It may be used to recover petroleum-polluted locations (Hohener and Ponsin 2014).

14.1.8.8 Bioslurping

This is a mixture of bioventing and vapour processing. It supplies an indirect source of oxygen (Gidarakos and Aivalioti 2007) and draws liquid in a stream by means of a pumping system. The biological procedures in this treatment refer to the aerobic biological degradation of hydrocarbons in the unsaturated area when air is introduced (Kim et al. 2014).

14.1.8.9 Biosparging

This technique is like bioventure. By better aeration, microbial activity is increased. Unlike bioventure, more ventilation is carried out in the saturated zone to allow those compounds that are volatile to move into the unsaturated area, promoting biodegradation (Philip and Atlas 2005).

14.1.8.10 Special Features of Bioremediation

- It is an environmentally friendly method with low labour, time and facility costs. It is secure. It is widely accepted by the public for treatment of waste at contaminated soils. It is risk-free as the amount of microbes decreases by itself when contaminant is removed. The residuals of the therapy are therefore completely harmless.
- The benefit of low cost and applicability over most polluted sites results in minimal disturbance to ordinary operations around the polluted site. There is no need to carry waste off-site, so any health and environmental risks that could occur from carrying toxic contaminants can be minimized.
- It guarantees that the pollutants are completely destroyed and that dangerous compounds are converted into harmless substances without any potential burden for processing and disposal of contaminated material.
- No dangerous chemicals need be introduced on the polluted site. The nutrients added to aid the development of microbes are only fertilizers commonly used in lawns and gardens that are not harmful.

14.1.9 Limitations of Bioremediation

- Only those compounds that are biodegradable are restricted to the applicability of bioremediation. Not all compounds can be degraded quickly and completely.
- Highly site-specific factors affecting the efficiency of biological restoration include the existence of metabolically competent microbial communities,

appropriate circumstances for microbial growth and suitable concentrations of nutrients and pollutants.

- Further study is necessary to bioremediate complicated contaminant mixtures as biodegradation variables in this situation are not yet been well known.
- Finally, bioremediation is limited by the longer processing time than standard alternatives, such as soil excavation and extraction or incineration.

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