BIOREMEDIATION: A SUSTAINABLE APPROACH TOWARDS ENVIRONMENTAL DETOXIFICATION

Abstract

Environmental pollution reached to alarming level in past few decades due to various anthropogenic activities and industrialization. Pollution caused by xenobiotics and other refractory substances are now recognized as major issue to both humans & the environment. A variety of toxicants, such as heavy metals, hydrocarbons, aromatic compounds, plastic material, and other chemical compounds, are the predominant pollutants in the environment due to their non-biodegradability and adverse effects. Bioremediation is a rapidly growing remediation method for eliminating toxicants from contaminated sites. In order to detoxify harmful pollutants, bioremediation uses a variety of bacteria that can act simultaneously or sequentially. Bioremediation also referred as an acceleration of the normal degradation by microorganisms, plants and with the help of their enzymes degradation or conversion of toxicants into less toxic compounds including CO_2, water, microbial biomass, inorganic salts, and other by-products (metabolites). It is a process that eliminates, degrades, detoxifies, and immobilizes potentially hazardous contaminants and pollutants. The basic purpose of bioremediation is to degrade pollutants and transform them to less harmful forms. Based on criteria such as expenses, type of pollutant, and its quantity, appropriate strategy of bioremediation may be applied. Present article reveals comprehensive glance about the process of various types of bioremediation with its merits and drawbacks.

Keywords: Bioremediation, toxicants, pollutants, environment, detoxification, pollution

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I. INTRODUCTION

Global industrialization has led to environmental pollution. Due to anthropogenic activities, such as mining, release of heavy metal effluents from steel factories, manufacturers of battery, energy production adversely affect the environment. As a result of this vast quantities of inorganic and organic pollutants are added into the environment every year. Sometimes, such discharges are intentional and well monitored (e.g., emissions from industry) on the other hand it can be accidental which includes oil spills, chemical spills, gas leak, etc. Such substances are often harmful and less biodegradable which results in accumulation and biomagnification. Many of these contaminants can cause mutations in the humans and harm environment. The brain, liver, and kidney accumulate heavy metals via absorption. Animals may also experience damage to the nervous system, cancer, growth retardation, other negative effects as well as death. Heavy metal in soil inhibits absorption of nutrients, metabolism process, and plant growth which reduces production quality as well as quantity. Removal of such environmental contaminants using bioremediation techniques is a practical and affordable solution. The term "remediate" refers to "to fix a problem," while "bioremediate" implies to solve an environmental issues like polluted soil, contaminated groundwater with the help of living organisms. Soil polluted by xenobiotics or heavy metals can be remediated via physical, chemical & biological process. But, physical & chemical approaches generates much of the waste and pollution, making them ineffective. Bioremediation is a environmentally responsible method that uses natural biological methods to completely eliminate dangerous or toxic contaminants. Any process which recovers original environment affected via contaminants to its natural state using microorganisms, plants, or enzymes is called bioremediation. Ex-situ & in-situ are the two kinds of bioremediation technique. The process of ex-situ bioremediation involves removal of pollutants or contaminants from the area and treating it somewhere else, while in-situ bioremediation process cleanses the contamination at its actual location. Examples of bioremediation techniques include landfarming, bioslurries biofiltration, bioventing, biopiles, compositing, natural attenuation, bioaugmentation, bioslurping, and biostimulation. Microorganisms that carry out the bioremediation process are known as bioremediator. For effective bioremediation, microbes should enzymatically react on contaminants and transform them into less toxic compounds. Since bioremediation can be successful in favorable environmental conditions that support microbial growth and activity, its application often requires modification in environmental conditions in order to promote microbial proliferation and rapid degradation. Bioremediation procedures are often less expensive than conventional methods like combustion, and certain contaminants can also be remediated at its actual location, that reduces exposure hazards to the cleaning workers or broader exposure due to transportation mishaps. As bioremediation is works on natural attenuation, it is more acceptable to the public than other techniques.

II. PRINCIPLE OF BIOREMEDIATION

"Bioremediation" means the biological metabolism of organic wastes under regulated conditions and by providing favourable conditions to the living organism or their enzymes to work efficiently. The hazardous compounds can be destroyed or detoxified through bioremediation. Each step of metabolism process requires enzymes from classes - oxidoreductase, transferase, hydrolase & lyase. Most other enzymes may break down a variety of substrates due to affinity for both specific and nonspecific substrates. For the efficiency of bioremediation, contaminants need to be subjected to the enzymatic activity. Environmental factors frequently need to be changed during bioremediation in order to hasten microbial growth and breakdown .This is due to the fact that bioremediation only functions when the conditions are favourable for bacteria to grow and disperse. The natural and encouraged process of bioremediation can be aided by organisms and fertilizers. Biological degradation of toxicants is the key component of bioremediation technique. It is the process of biotransformation of toxic substances or pollutants into harmless compounds or safe inorganic substances that exist naturally.

III. TYPES OF BIOREMEDIATION

According to Marykensa (2011), there are two categories of microbes mediated bioremediation process: ex-situ and in-situ. In-situ bioremediation is the process of cleaning up polluted water and soil at its actual location. This process is incredibly effective yet economical. In order to perform bioremediation, it entails the use of nonpathogenic microorganisms (Gomes et al., 2013).Remediation of petroleum-contaminated environment is the predominant application of in-situ bioremediation. Because microbes can enter the contaminated region via their chemotactic capacity, chemotaxis is important (Jorgensen, 2007). To boost proliferation of microbes, in-situ approach requires an aerobic technique that involves introducing oxygen in soil via bioventing & hydrogen peroxide injection (Brown et al., 2017).In-situ bioremediation has certain significant drawbacks, including the slow rate of decomposition and the ability of microbes to survive on waste materials in soil. (Hao Chang et al., 2013).In-situ bioremediation is more appealing and affordable as it is less disruptive and does not need soil extraction and transportation of the polluted soil. Amongst the most often used in-situ approaches include natural attenuation, bioventing, bioslurping, biostimulation and bio-augmentation..

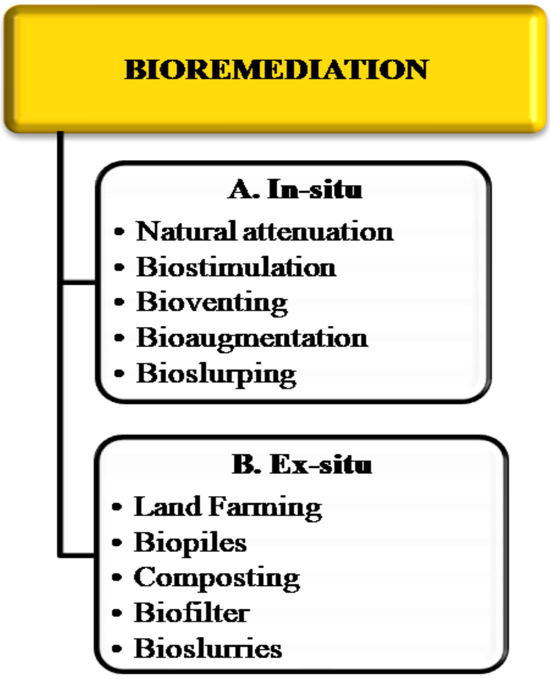

Figure 1: Various Bioremediation approaches

1. **Natural Attenuation:** Natural attenuation refers to a natural method to remove pollutants. While considering this method to remediate affected sites (contaminated sites) typically requires modelling and assessment of pollutant degradation rates, pathways of exposure , effects on sensitive receptors, an estimate of the concentration of pollutants downgradient to the polluted plume in case the plume migrates. This strategy's suitability is often assessed on a case-by-case basis. This strategy isn’t a straightforward process, it needs interdisciplinary abilities in hydrogeology, chemistry, microbiology, and geochemistry**.**

2. **Biostimulation:** For the growth and survival of naturally occuring communities of microbes, biostimulation provides an appropriate nutritional and physiological environment. As a result, the pollutants are reduced by metabolic activity rapidly.

3. **Bioventing:** Bio-venting is also an approach of designed in-situ remediation technique that increases the naturally occurring biological degradation of a few degradable contaminants under aerobic conditions, including non-chlorinated VOCs (volatile organic compounds) and SVOCs (semivolatile organic compounds), like petroleum hydrocarbons located in the vadose (unsaturated) zone by providing oxygen to pre-existing microbes that are aerobic (USEPA 2006). It uses low air flow & offers a little oxygen amount essential for biological degradation while reducing volatilization and release of pollutants into the ecosystem. This approach is more efficient when the polluted sites are hot and water level is lesser than the surface.

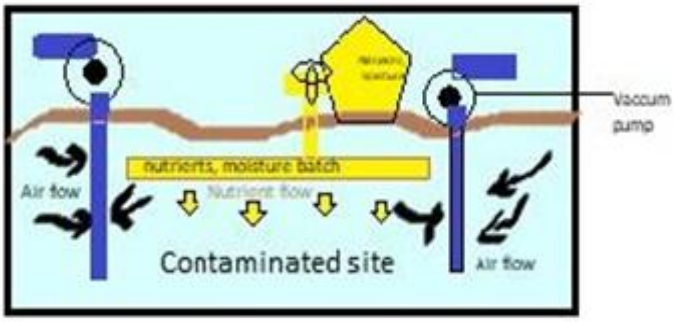

Figure 2: Bioventing

4. **Bioaugmentation:** The incorporation of strains or cultures to contaminated sites to accelerate contaminant degradation is known as bioaugmentation. This approach can target specific chemicals, such as refractory organics. Microorganisms that are already present in the environment can break down contaminants, but only at a very slow rate. This technique is utilized to overcome the problem of a slower rate.

5. **Bioslurping:** It is a multiphase separation approach, an effective in in-situ bioremediation technique which combines vacuum-augmented free product recovery through bioventing of soil beneath the surface to concurrently restore soil, sediment, and groundwater polluted by Poly aromatic hydrocarbons (PAHs). Bioventing encourages the aerobic decomposition of pollutants that remain in contaminated soil, vacuum-enhanced recovery, on the other hand, uses a negative pressure for creating a sort of vacuum and draws water and free product from underground.

6. **Ex-situ** technique requires extraction and elimination of polluted soil for on-site treatment or transportation to appropriate locations prior to the treatment. Bio-slurries, land farming, and biopiles are commonly used ex-situ bioremediation techniques. Ex-situ bioremediation is the process that treats pollutants, contaminated soil, or water after it has been removed from the original location.

7. **Land farming**: Land farming is an ex-situ remediation technique where polluted soil, sludge, or sediment is dug and spread upon a previously prepared bed, then repeatedly turned over (tilled) so as to aerate the entire mixture till pollutants are degraded by using stimulated aerobic microbes in the soil triggered by aeration and by the provision of nutrients , minerals, and moisture. This method is only suitable for treat top 10 to 35 centimeter of soil.

8. **Biopiles:** It is an ex-situ biological remediation procedure that combines buried soil, sludge, and sediment with soil amendments, deposited over the site of treatment, subsequently remedied through forceful aeration. The technique entails layering polluted soil, dry sediments or sludge in pile and boosting aerobic microbial community biodegradation activity by providing favourable conditions inside the pile (Germaine et al. 2012).The contaminated soil, sludge, or silt is often dumped on top of the treated soil in biopiles, that are typically 2-3 meters tall.

9. **Composting:** Composting (windrows) is a regulated biological procedure where polluted soil after excavation is blended with bulking ingredients and organic compounds (such as shredded wood, dried grass, other foliage, manure, and biodegradable organic waste) in appropriate quantities to maintain balance between nitrogen (N) & carbon (C) required for thermophilic microbial activity maintenance. Organic pollutants like DDT (1, 1, 1-trichloro-2,2-bischlorophenyl ethane), PAHs (polycyclic aromatic hydrocarbons), are transformed to non-toxic or less toxic products (stable) by microbes activity throughout the composting process. The exothermic processes carried by existing bacteria while degrading organic material causes rise in temperature to 55°-65° C (thermophilic conditions) throughout the procedure, this is essential for proper biotransformation of harmful pollutants.

10. **Biofilter:** This technique is an oldest and mostly used to remove gaseous contamination. Columns embedded with microorganisms are employed in this technology to eliminate gaseous contaminants (Boopathy, 2000). It is an important isolation technique for removing organic pollutants from air and water. The efficacy of biofilters is determined by the time that wastewater remains inside the system as well as particle size distribution in filter material. (Van Os et al., 1998).

11. **Bioslurries:** This remediation is a combination of different bioremediation processes. As compared to compost method, in which polluted soil has water just in a trace quantity, whereas this method blends affected soil & water to form a slurry which has higher quantity of water than soil, that merely lowers amount of toxicants to minimize pressure on microbes and also improves organic pollutants diffusion rate to increase pollutants & microbes interaction .This whole process is done in a reactor, that prevents emission of organic compounds through volatization & thereby protects the environment.

IV. MERITS & DEMERITS OF BIOREMEDIATION

A serious public health problem is environmental pollution, since it negatively affects living organisms including environment. Available chemical and physical remediation procedures are expensive to completely remove contaminants. Both strategies mayincrease pollution and destabilize the site, which could have a detrimental impact upon ecosystem including the local people. Therefore, the techniques of remediation that rely on physical and chemical force aren't considered as environmentally sustainable.

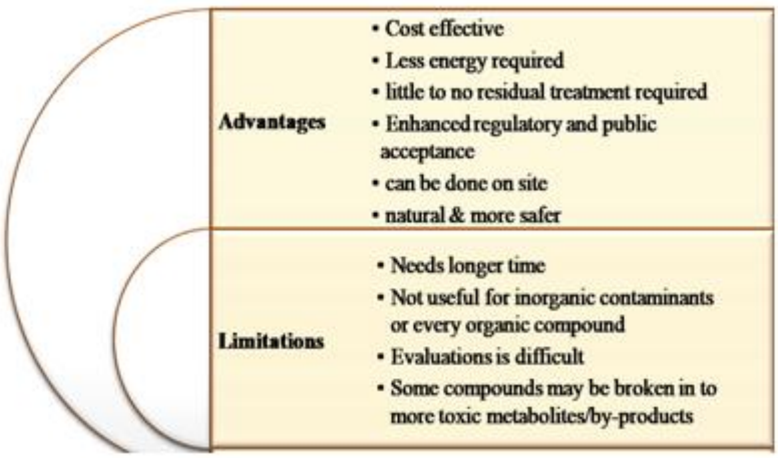

Figure 3: Advantages & Disadvantages of Bioremediation Technique

Contrary to these techniques, bioremediation depends on biological processes (through various kinds of organisms) to eliminate various persistent pollutants. Each method of bioremediation has a distinct set of applications due to their own pros and flaws. Unlike several other techniques; bioremediation too has few disadvantages. Few pollutants, including organic chlorinated compounds or aromatic hydrocarbons are resistant to microbial degradation. They may degrade at a slower rate or may not undergo degradation. There are no standards for determining whether a pollutant may be degraded, making it difficult to estimate the rate of bioremediation.

Table 1: Case studies on bioremediation of various contaminants

Contaminated Site / Sample	Pollutant	Method of Clean Up	Inference	Reference
Soil (Borhola oil fields)	Petroleum hydrocarbon	micro slurry reactor	Within a year, the components of crude oil were reduced by 75% using nutrient and microbe-enriched solutions with adequate aeration.	B.K. Gogoi et. al (2001)
River Water (Mutha RIVER, Pune)	heavy metals- Lead (Pb), arsenic (As), Mercury (Hg) and Zinc (Zn), chlorides, phosphates and nitrates	Bioaugmentation> biostimulation	Bioaugmentation was more effective than biostimulation with aeration and nutrient in eliminating a variety of organic pollutants from lake sediments.	G S Anaokar et.al (2012)
Liquid waste oil	Aliphatic & aromatic hydrocarbon compounds	Bioreactor	With adequate oxygen supply, the speed and acceleration of microbial growth rates increase. It increases rate of bioremediation.	Hasmway (2013)
Synthetic wastewater	Selenium	Jar fermenter (From the aqueous phase, bio volatilization.)	In a simple gas trap with nitric acid, 82% of the selenium (Se) volatilized by variant NT-I was obtained along with minor impurities, revealing that variant NT-I is a promising bio catalyst for Se recovery.	_Kagami et.al (2013)
Soil	Pentachlorophenol (PCP) Pesticide	Microorganism mediated	Flavobacterium sp. cultures degraded PCP more efficiently in Columbia soil than Arthrobacter sp. cultures. The mixed culture proved the most effective at degrading PCP.	SujataRay (2014)

Aqueous stock solution of 10 ppm for MO (methyl orange), Cr (chromium) and Pb (lead)	MO (methyl orange), Cr (chromium) and Pb (lead)	Biosorption by dead fungal biomass of *Aspergillus flavus*.	After 5 cycles of desorption processes, biosorption capacity towards Pb, Cr, and MO at 76%, 72%, and 53% respectively was observed by *Aspergillus flavus* dead fungal biomass	Mahmooda Takey et. al (2014)
Kulv river water	(NH3-N) Ammonia nitrogen , SS (suspended solid) , TN (total nitrogen), and TP (total phosphorus)	mussel-microalgae-bacteria system	After several months of treatment, the aquatic environment was improved by the mussel- microalgae-bacterial system and had a low operating cost.	Bing Geng et.al (2021)

V. CONCLUSION

Pollutant deposition in the environment has reached a critical point in recent years due to urbanization, growth of population, and expansion of industries. The only environmentally responsible solution to solve such issues is biological remediation, which can be accomplished in two different methods called in-situ and ex-situ. Area characterization is the initial stage for efficient bioremediation since it helps to opt for the most effective and practical ex-situ or in-situ bioremediation method. Under controlled conditions this technique can be utilized to treat a wide spectrum of contaminants. As compared to various other techniques which are frequently utilized to clear noxious waste or toxic compounds. Bio-remediation is one of the less expensive, safe and more acceptable technique of remediation which has a number of economic or efficiency benefits. Hence, geological features of the contaminated area(s), including the type of soil, pollutant depth and type, site proximity to human habitation, along the criteria of each bioremediation approach, should be taken into account if one wants to treat contaminated sites efficiently.

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