BIOREMEDIATION: HARNESSING NATURE'S POWER FOR ENVIRONMENTAL CLEANUP

Abstract

The growing rate of urbanization and industrialization has led to an increase in several types of pollution caused by the release of toxic chemicals to the environment. This is usually perpetuated by the manufacturing industry (e.g. detergent and dye), agricultural sectors (e.g. fertilizers and pesticides), mining industry (e.g. cyanide and sulphuric acid) and construction companies (e.g. cement and metals). Bioremediation is an effective cleaning technique for removing toxic waste from polluted environments that is gaining popularity.

Various microorganisms, including aerobes and anaerobes, are used in bioremediation to treat contaminated sites. Microorganisms play a major role in bioremediation, given that it is a process in which hazardous wastes and pollutants are eliminated, degraded, detoxified, and immobilized. Pollutants are degraded and converted to less toxic forms, which is a primary goal of bioremediation. Ex situ or in situ bioremediation can be used, depending on a variety of factors, such as cost, pollutant types, and concentration. As a result, a suitable bioremediation method has been chosen.

Keywords: Bioremediation, Types of Bioremediation, Intrinsic Bioremediation

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The rapid increase in the world's population has resulted in a greater demand for natural resources and sources to meet the population's high needs for food, energy, and other necessities. The industrial revolution was a response to these demands, but it also brought about the manufacturing of a vast array of different organic and inorganic compounds, which have both directly and indirectly contributed to the habitats' ongoing contamination. Their challenging biodegradability is thought to be the reason for the length of the pollution. Even in the deepest ocean waters, detectable quantities of contamination are found due to the rapid and widespread trend of environmental pollution. Only around 10% of total trash were safely disposed of, according to estimates from the environmental protection agency (EPA) (Chaudhry 1994; Reddy and Mathew 2001).

Today, we want to shed light on an innovative and eco-friendly approach to environmental cleanup called bioremediation. This fascinating process utilizes the power of nature to restore contaminated sites and mitigate pollution.

I. WHAT IS BIOREMEDIATION?

1. **Bioremediation:** The term of bioremediation has been made of two parts: “bios” means life and refers to living organisms and “to remediate” that means to solve a problem.

   The term "bioremediation" is derived from two components: "bios," which pertains to life and signifies living organisms, and "remediate," which means to address or resolve a problem. Bioremediation is a field within biotechnology that harnesses living organisms, such as microbes and bacteria, to eliminate contaminants, pollutants, and toxins from various environments, including soil and water. This process entails the detoxification, reduction, degradation, or transformation of toxic chemicals into less harmful substances. Bioremediation serves as a waste management technique that leverages organisms to extract or utilize pollutants from polluted areas.

   Numerous methods are employed to purify contaminated water or solid materials, ranging from chemical treatment and incineration to landfill disposal. Various waste management techniques, including solid waste management and nuclear waste management, exist. However, bioremediation stands apart by avoiding the use of toxic chemicals. Instead, bioremediation utilizes living organisms such as bacteria, fungi, and plants to enzymatically degrade or neutralize hazardous substances present in the environment. These organisms possess distinct metabolic capabilities that enable them to convert pollutants into less harmful forms. Leveraging these natural processes allows for the effective cleanup of polluted areas without exacerbating environmental damage.

   In the bioremediation process, microorganisms, particularly bacteria and fungi, play a central role. Among these microorganisms, bacteria are of paramount importance as they are responsible for breaking down waste into essential nutrients and organic matter. However, it's important to note that while bioremediation is an effective waste management method, it may not completely eliminate all contaminants. Bacteria excel at digesting certain contaminants such as chlorinated pesticides or effectively cleaning up oil spills. However, it's worth mentioning that microorganisms are unable to fully eradicate heavy metals like lead and cadmium.

Theoretically, bioremediation can be thought of as a helpful strategy for the total annihilation of a wide variety of contaminants because there are sufficient bioremediants in nature to be utilized against a large range of pollutants. Numerous substances that are deemed harmful and dangerous by law can undergo biotransformation to become innocuous products. By doing this, the possibility of future liability for handling and getting rid of tainted material is eliminated. It is feasible to completely destroy target pollutants rather than transmit them from one environmental medium to another, such as from land to water or air.(Alvi, 2001).

2. **Concept of Bioremediation:** Bioremediation is described as the utilization of living organisms to eliminate or reduce pollutants from soil, water, or wastewater, as defined by the United States Environmental Protection Agency (US EPA) (Cristaldi et al., 2017). This process can involve the participation of green plants, which have the ability to absorb pollutants from the soil or water through their roots and accumulate them in their leaves. Microorganisms can also be employed to detoxify or eliminate inorganic pollutants from the environment (Khalid et al., 2017). Bioremediation provides a long-term, in situ solution rather than merely relocating the issue. It is a viable approach for remediating soil or water contaminated with heavy metals, metalloids, or other inorganic pollutants (Ali et al., 2013; Ashraf et al., 2019). This method has been proven to be cost-effective, efficient, innovative, environmentally friendly, and powered by solar energy, enjoying substantial public acceptance in comparison to engineering techniques like excavation, soil incineration, soil washing, flushing, and solidification (Ali et al., 2013; Sarwar et al., 2017). The effectiveness of bioremediation in removing inorganic pollutants typically relies on various factors related to plants, microbes, and the soil or water, including the physicochemical characteristics of the soil or water, microbial and plant exudates, as well as the ability of living organisms to absorb, accumulate, sequester, transport, and detoxify pollutants (Khalid et al., 2017).

II. HOW DOES BIOREMEDIATION WORK?

There are two main types of bioremediation: In situ and ex situ.

1. **In Situ Bioremediation:** In this method, biodegradable materials or microorganisms are applied directly to the contaminated site. The microorganisms then utilize the pollutants as a source of energy or nutrients, effectively degrading them in place. This approach is particularly useful for soil and groundwater remediation.

2. **Ex Situ Bioremediation:** Ex situ bioremediation involves excavating contaminated material and treating it outside its original location. This allows for more controlled conditions during the remediation process. Contaminated soil or water is typically treated in specially designed bioreactors that provide optimal conditions for microorganisms to thrive and break down pollutants.

III. HOW DOES BIOREMEDIATION WORK?

1. **Microbial Bioremediation:** Microorganisms such as bacteria, fungi, and algae are employed to degrade organic contaminants like petroleum hydrocarbons or industrial chemicals. These microorganisms feed on the pollutants as an energy source, effectively breaking them down into harmless byproducts.

2. **Phytoremediation:** Plants play a crucial role in phytoremediation by absorbing contaminants through their roots and accumulating them in their tissues. They can remove heavy metals, pesticides, and other pollutants from soil or water. Additionally, some plants have the ability to break down complex organic compounds through metabolic processes.

Types of Bioremediation

Bioremediation is of three types,

1. **Biostimulation:** The bacteria are triggered to start the process, as the name implies. First, the polluted soil is combined with unique nutrients and other essential elements in liquid or gaseous form. It promotes the proliferation of microorganisms, which enables them and other bacteria to quickly and effectively remove pollutants from the environment.

2. **Bioaugmentation:** In certain instances, specific locations necessitate the involvement of microorganisms to eliminate contaminants, such as in municipal wastewater treatment. In such unique scenarios, the method of bioaugmentation is employed. However, this approach has a significant limitation: it can be exceedingly challenging to regulate the proliferation of microorganisms while targeting the removal of the specific contaminant.

3. **Intrinsic Bioremediation:** Intrinsic bioremediation is particularly efficient when applied in soil and water environments, as these biomes frequently harbor a substantial likelihood of contamination and toxins. This bioremediation method is predominantly employed in subterranean locations, such as underground petroleum tanks. In such settings, detecting leaks can be challenging, allowing contaminants and toxins to potentially infiltrate and contaminate the stored fuel. Consequently, microorganisms play a pivotal role in eliminating these toxins and decontaminating the tanks.

4. **Bioreactors:** The biological treatment of relatively modest volumes of waste by use of enclosed areas or reactors with biological activities. Liquids or slurries are treated using this technique. For the ex situ treatment of polluted soil and water pumped up from a contaminated plume, slurry reactors or aqueous reactors are utilized.Reactor bioremediation is passing polluted water or solid material (soil, sediment, sludge) via a specially designed containment system.Petroleum residue-contaminated soil and other materials have been treated in bioreactors (McFarland et al. 1992; De´ziel et al. 1999).

5. **Bioventing:** Pulling oxygen through the tainted medium in order to promote the development and activity of microorganisms. The most popular in situ therapy is called "bioventing," which entails introducing nutrients and air into contaminated soil via wells in order to encourage the growth of local microorganisms. Bioventing reduces

volatilization and the release of pollutants into the atmosphere by using low air flow rates and supplying only the amount of oxygen required for biodegradation. It can be applied in situations when pollution is deeply ingrained and is effective for simple hydrocarbons (Vidali 2001). Effective oxygen diffusion for desired rates of bioremediation in many soils is limited to a few centimeters to approximately 30 cm into the soil, while in certain circumstances, depths of 60 cm and beyond have been successfully treated (Vidali 2001).

6. **Biopiling:** Composting and land farming are combined to create biopiles. Engineered cells are essentially built like composting piles with air. Because of the organic compost matrix's structure, adding compost to contaminated soil improves bioremediation (Kastner and Mahro 1996).According to Wohlmann and Steinhart (1997), compost accelerates the oxidation of aromatic pollutants in soil to ketones and quinones, which finally vanish. They are a more sophisticated form of land farming that usually controls the physical losses of the contaminants through leaching and volatilization. They are typically employed for the treatment of surface pollution with petroleum hydrocarbons. For native aerobic and anaerobic bacteria, biopiles offer a suitable habitat (Vidali 2001).A full-scale approach known as "biopile treatment" involves combining excavated soils with soil additives, placing them on a treatment area, and then utilizing forced aeration to bioremediate the soil.

IV. ORGANISMS INVOLVED IN BIOREMEDIATION PROCESS

According to Alexander (1994), organisms intended for use in bioremediation must meet the following criteria: (a) they must possess the useful enzymes needed for the process; (b) they must be able to survive and exhibit their bioactivity in polluted environments; (c) they must be able to reach the contaminant, which may not be soluble in water or be heavily adsorbed to solid surfaces; (d) the contaminant's substrate site must be accessible for the active site of the enzyme involved in bioremediation; (e) the contaminant and the enzymatic system must come into close contact somewhere within or outside of the cell; and finally (f) suitable environmental conditions must exist or be supplied for the population of the potential.

Many uni- and multicellular organism types possess the necessary potentials to be used in bioremediation procedures. It is true that certain plant, bacterial, and fungal species can be employed to eradicate contaminants. However, because they are naturally occurring decomposers in a variety of habitats and have a high potential for bioremediation, microorganisms have the most promise. The compounds that have synthetic or natural origins are broken down and degraded by microorganisms such as bacteria and fungus.

The kind of bioremediation known as phytoremediation uses plants and algae as bioremediants. Fungi are used as bioremediants in a process known as mycoremediation. 2003; Levin et al.

1. Advantages of Bioremediation

- **Environmentally Friendly:** Bioremediation offers a sustainable solution that minimizes environmental impact compared to traditional cleanup methods that rely on chemicals or excavation. The most significant advantage of adopting bioremediation technologies is the positive impact on the environment. Nature is used to fix nature in bioremediation.

- **Cost-Effective:** In many cases, bioremediation can be a more cost-effective option compared to other cleanup techniques since it requires fewer resources and infrastructure.
- **Versatile Applications:** Bioremediation has proven successful in treating various types of contaminants, including petroleum hydrocarbons, heavy metals, pesticides, and even radioactive materials.
- **Long-Term Solution:** Bioremediation not only removes pollutants but also promotes the natural restoration of ecosystems. It allows for the regeneration of habitats and the return of biodiversity to previously contaminated areas.
- **Safest And Least Invasive:** This is the safest and least invasive soil and groundwater treatment available when properly done by skilled workers using specialised bioremediation equipment.
- **Highly Treatable:** Bioremediation is an effective way to treat a wide range of pollutants, including ammonia and phosphates, as well as organic pathogens, metals, arsenic, fluoride, nitrate, and volatile organic compounds.
- **Removal of Pesticides And Herbicides:** It performs effectively in eliminating seawater intrusion and pesticides and herbicides from aquifers.
- **No Risk of Transportation:** The majority of the time, work is completed on-site to minimize transportation hazards.
- **Less Requirement Of Equipment:** Except for specific parts, very little equipment is required.
- **Low Maintenance Cost:** Maintenance costs are low, and input costs are low.
- **Reduction Of Liability:** Liability is reduced since toxins are less likely to escape.
- **Low Energy Consumption:** In comparison to incineration and landfilling, there is very little energy consumed.

2. Bioremediation – Disadvantages

- **Treats Only Biodegradable Substances:** The primary limitation of bioremediation technique is its exclusive ability to handle biodegradable chemicals.
- **Hazardous New Product:** Additionally, scientists have shown that occasionally the new product that results from biodegradation is far more hazardous to the environment than the original component.
- **Time Consumption:** Lastly, the process requires time, especially for ex-situ bioremediation, which involves pumping and excavation.

V. CONCLUSION AND PERSPECTIVE

In conclusion, bioremediation represents a promising approach to environmental cleanup, harnessing the power of nature to restore contaminated sites. By leveraging the incredible abilities of microorganisms and plants, we can work towards a cleaner and healthier world for future generations. World is moving towards promoting sustainable practices and providing innovative solutions for environmental challenges. Bioremediation is just one of the many ways we are working towards a cleaner future.

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