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Bioremediation of polluted water based on different technologies

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Abstract : This paper briefs about the bioremediation process for the polluted water and its needs. Microorganisms and contaminants' ecological interactions were clearly expressed here. The methods and forms of phytoremediation (phytoextraction, phytodegradation, rhizofiltration, Phyto stabilization, phytovolatilization) were thoroughly reviewed and followed by remediation process, which was not a popular method of contaminated bioremediation. Other bioremediation methods, such as adding nutritional activators or surfactants, precipitation, ion exchange, etc., were not cost-effective and could not be extensively used. In order to produce a review of the synergistic interaction between environmental impact and the fate and behavior of environmental contaminants, efforts were made to select and perform the bioremediation technique that is the most effective as well as another pertinent technique that can sustain the efficient and effective operation and monitoring of a bioremediation process. These efforts included the selection and performance of the most effective bioremediation technique. The primary effect elements (for example, biological factors, environmental factors, contaminants), as well as the major benefits and drawbacks of bioremediation were explored in this paper. A variety of natural and human-caused phenomena through wastes into water, particularly the growth of human industrial civilization and the rapid advancement of modern life, have degraded plentiful water resources. Bioremediation can destroy a wide range of substances that are legally considered harmful. Treatment residues are normally non-harmful to the environment. Bioremediation has been shown to be less expensive than other methods of removing pollutants. It also removes potential risks to human health and the environment. In summary, this paper provides an outline of the current state of affairs as well as future application areas.

I. INTRODUCTION

Bioremediation is an emerging technology that, in conjunction with other physical and chemical treatment methods, can be used to control an extensive range of environmental pollutants (Singh, P., et al., 2019). Bioremediation is a biological technology that employs inexpensive and low-pollution remediation techniques. These strategies are well-received by the public and can be implemented on sites. In numerous nations around the globe, bioremediation has been implemented. Numerous natural and manmade factors, such as the rise of industrial civilization and the acceleration of contemporary life, have contributed to the contamination of vast water resources. Bioremediation has the potential to degrade a vast array of potentially hazardous chemicals. Treatment residues are typically innocuous to the environment. It can be demonstrated that bioremediation is less expensive than other technologies for removing contaminants (Cheng, J., 2014).

Human life on Earth depends on global water quality. It is estimated that 7.5 liters of water per person per day are needed for drinking, food preparation, and personal hygiene, and 50 liters per person per day are needed for all personal hygiene, food hygiene, domestic housekeeping, and washing needs (Howard, G., & Bartram, J., 2003). Even in prosperous societies with high per-capita home water usage, agriculture and ecosystems outweigh it (Data360, 2010). Environmental quality gradually deteriorates as pollution levels rise. Because of the production, use, and disposal of hazardous substances, a condition has been created that challenges our global society to find effective remediation solutions to reverse the harmful conditions that constitute a serious threat to human and environmental health. These solutions must be able to reverse the harmful conditions without causing further damage to the environment. The number of polluted areas that are anticipated to exist is substantial, and this issue affects the entire world (Cairney, T., 1993).

Bioremediation primarily employs microorganisms like yeast, fungi, or bacteria to purify polluted water (Strong, P. J., & Burgess, J. E., 2008). Microbes are an essential component of natural cycles and the driving force behind bioremediation in polluted environments (Bonaventura, C., et al., 1996). Introducing a terminal electron acceptor, encouraging development through the provision of nutrients, modulating humidity and temperature conditions, and other methods can be used to establish microbial groups (Smith, V. H., et al., 1998). During bioremediation, microorganisms utilise pollutants as sustenance or energy sources (Tang, C. Y., 2007).

In reaction to the ineffectiveness and potentially dangerous side effects of conventional waste treatment approaches, the field of bioremediation has arisen over the course of the past few decades. Bioremediation, which utilises microorganisms and their metabolic activities to destroy toxins, is viewed as a cost-effective alternative to conventional remediation approaches since it is safe, reliable, generally efficient, and ecologically acceptable. Ex situ bioremediation and in situ bioremediation are both viable approaches (Tyagi, B., & Kumar, N., 2021).

1. PRINCIPLES OF BIOREMEDIATION

Through biodegradation, microorganisms breakdown organic contaminants into simpler chemicals. The overwhelming majority of biodegradable substances are organic and originate from plant and animal debris. Industrialization has produced many toxic substances, including recalcitrant classes like polycyclic aromatic hydrocarbons, toxic dyes, pesticides, and heavy metals. These substances pose a serious threat to the environment as a result of their mutagenic and carcinogenic effects on humans, plants, and aquatic organisms. Industrialization has led to the production of a large number of toxic substances. The process by which microorganisms spontaneously break down more complicated organic chemicals into more straightforward inorganic forms is known as biodegradation. Bioremediation uses microorganisms to remove toxins through natural attenuation, biostimulation, or bioaugmentation. This is bioremediation. Bacteria, fungi, algae, and protozoa degrade environmental pollutants. To maximize microorganisms' biodegradation of organic matter under ideal conditions, certain criteria must be established (Fouad, F. A., 2023). Microorganisms eat this substance as food and transform it into smaller chemicals via enzymatic or metabolic activities. It cleans up polluted areas and prevents new pollution. Bioremediation relies on microorganisms' organic breakdown. Algae, fungi, and bacteria solubilize, transport, and deposit metals and detoxify dyes and complex chemicals. Toxic waste compounds can be gaseous, liquid, or solid, so bioremediation methods vary (Shilpa, K., 2018).

2. BIOREMEDIATION WITH DIFFERENT TECHNOLOGIES

Bioremediation is done with number of different technologies for the treatment of polluted water, those are as below:

2.1 Phytoremediation:

Phytoremediation uses plants to remove or transform hazardous substances from soil and groundwater. Plants can extract and concentrate environmental components, making environmental cleanup more sustainable. Plant tissue that has become contaminated over time can be safely collected and treated. Plant roots can also degrade pollutant species or draw polluted groundwater to the surface, exposing contaminant species to microorganisms in an oxygen-rich environment. Both involve phytoremediation. According to Bioremediation Technologies in 2005, the following procedures are carried out:

2.1.1 Phytoextraction: Phytoextraction was originally used to recover heavy metals from soils, but it can now be applied to more materials and media. The 1960s introduced phytoextraction. Current research focuses on heavy metal and radionuclide removal from water. Hydroponic systems in greenhouses are being used to study plants with high contaminant root uptake but poor branch translocation (Cunningham, S. D., et al., 1997). Their metabolic processes make them hyperaccumulators. Plants with high growth rates (more than three tons of dry matter per hectare per year) and the ability to withstand high metal concentrations in harvestable plant portions (more than 1,000 milligrams per kilogram) are needed for practical treatment (Schnoor, J. L., 1997).

2.1.2 Phytostabilization: The use of phytostabilization to conserve metals at an existing site is extremely appealing when alternative cleanup processes are difficult to implement in large regions with low levels of contamination. In places where there is a significant concentration of metals, it can be difficult to make repairs since the soil itself is poisonous. Plants need to be able to withstand high levels of contamination, generate a significant amount of root biomass, immobilise toxins, and store contaminants in their roots (Miller, R., 1996).

2.1.3 Phytostimulation: Phytostimulation promotes rhizosphere microbial activity to decompose organic contaminants in soil. This process is also called improved rhizosphere biodegradation, plant-assisted bioremediation or degradation, and rhizodegradation. (4) Rhizosphere mycorrhizae fungi degrade organic contaminants that cannot be transformed aerobically. Root exudates contain sugars, carbohydrates, amino acids, acetates, and enzymes, which enrich indigenous microbe populations; (2) root systems bring oxygen to the rhizosphere, ensuring aerobic transformations; (3) fine-root biomass increases organic carbon; and (5) (Anderson, T. A., 1993). This method works well for removing pesticides, aromatics, and polynuclear aromatic hydrocarbons (PAHs) from soil and detritus (Miller, R., 1996). Demonstrations also focused on chlorinated solvents.

2.1.4 Phytotransformation: Phytotransformation is the process by which plants degrade and eliminate organic contaminants through metabolic processes or plant-produced compounds like enzymes. Organic contaminants are broken down into simpler compounds that plant tissue absorbs to grow. Pollutant uptake from the environment and accumulation in vegetation are necessary for phytotransformation. Phytotransformation may repair organic compound-contaminated areas. Plant enzymes can degrade and convert chlorinated solvents like trichloroethylene, ammunition residue, and pesticides. This method can remove toxins from petrochemical sites, storage areas, fuel accidents, landfill leachates, and agricultural chemicals. This method also removes fuel mishap toxins (Schnoor, J. L., 1997). The concentrated plant compounds must be non-toxic or safer than their precursors to be therapeutic. Phytotransformation can be used as a refining treatment or with other cleaning methods.

2.1.5 Rhizofiltration: The technique of utilising plant roots for the purpose of assimilating, concentrating, and precipitating hazardous metals from contaminated groundwater is referred to as rhizofiltration. In order to get the plants used to the environment, contaminated water is first given to plants that are suited and have strong root systems. After the roots of the plants have finished absorbing the toxins, the plants can then be harvested. The use of rhizofiltration makes in-situ treatment possible, which reduces the amount of environmental disruption. Due to the rapid growth of its roots, a plant that is ideal for the process of rhizofiltration has the ability to filter harmful metals out of a solution over a prolonged period of time. It has been discovered that a wide variety of plant species are able to successfully remove the metal ions

Cu (2+), Cd (2+), Cr (6+), Ni (2+), Pb (2+), and Zn (2+) from aqueous solutions (Dushenkov, V., 1995). The removal of low-level radioactive pollutants from liquid streams is another possibility that can be considered.

2.1.6 Constructed Wetlands: Constructed wetlands are human-made ecosystems that enhance natural biological, physical, and chemical processes to treat effluent, mine drainage, and other water. Constructed wetland rehabilitation can be productive, cost-effective, and eco-friendly. Constructed wetlands can also house species. Artificial wetlands can treat municipal wastewater, agricultural discharge, mine drainage, and other effluents. Constructed wetlands. These artificial wetland systems reduce BOD and TSS (Bastian, R. K., & Hammer, D. A., 2020).

3. BIOAUGMENTATION

A polluted area may benefit from bioaugmentation, which involves the introduction of certain or genetically modified microbes to the area. In the event that it is determined through site evaluations that native microorganisms are unable to digest the contaminants at issue, it may be conceivable to introduce exogenous microorganisms that possess the biochemical capabilities necessary to dispose of particular waste chemicals. The process of biodegradation is utilised in this approach. In the process known as biodegradation, microorganisms, most commonly bacteria and fungi, break down organic contaminants that are found in soil and groundwater. Organic pollutants decompose into carbon dioxide, water, and microbial cell mass in aerobic circumstances (in the presence of oxygen). Anaerobic conditions produce methane, trace amounts of carbon dioxide and hydrogen, and sometimes intermediate species that may be less poisonous, equally harmful, or even more lethal than the molecule being metabolized. PCP, lindane, DDT, and 2,4-dichlorophenol can all be broken down through the process of biodegradation. Bacteria and fungi such as Fusarium oxysporium, Phanerochaete Chyrysoporium, Pseudomonas cepacia, and Pseudomonas putida are responsible for the degradation of these pollutants (Kumar, R., & Sharma, C. B., 1992).

3.1 Biostimulation:

The practise of providing microbial communities in soil and groundwater with additional oxygen and/or inorganic nutrients is known as biostimulation. The promotion of the biodegradation of pollutants can be accomplished through the use of either in situ or ex situ approaches.

3.1.1 Bioventing: Bioventing encourages soil microorganisms to biodegrade contaminants in situ by providing air or oxygen. This is done in order to produce cleaner environments. Through the use of low air flow rates, bioventing is able to supply the vadose zone with just the right amount of oxygen to keep microbial activity going. Direct air injection is the method that is used most frequently in order to provide contaminated soils with oxygen. In addition to the decomposition of fuel residuals that is caused by adsorption, biodegradation of volatile chemicals can happen when vapours flow slowly through biologically active soil (Hoeppel, R. E., et al., 1991).

3.1.2 Chemical Oxidation of Soils: Redox reactions can transform the potentially harmful pollutants in the soil into chemicals that are either nonhazardous or less toxic. When electrons are moved from one chemical to another, the first compound undergoes oxidation, while the second compound undergoes reduction. Ozone, hydrogen peroxide, chlorine, hypochlorites, and chlorine dioxide are employed most often to treat dangerous contaminants. Effluent treatment and, more recently, pollutant remediation in soils are both examples of applications for the well-established and large-scale technology of chemical redox (Cookson, J. T., 1995).

3.1.3 Lagoon treatment: It is a method of in-situ bioremediation that destroys potentially harmful organic and inorganic chemicals in a lagoon. The contaminants might be organic or inorganic. In most cases, a combination of cleaning methods is required to achieve the desired results. Depending on the pollutants, aerobic or anaerobic biodegradation is possible. Both anaerobic and aerobic metabolic mechanisms are exploited for the treatment of wastes that contain volatile chlorinated hydrocarbons. In order to maintain high bioremediation rates, it is necessary for lagoon treatment facilities to make use of solids distribution and slurry mixing methods. Some of these methods include air sparging, pumping, mechanical dredging, and dredging (Cookson, J. T., 1995).

3.2 *Bioreactors:*

Bioreactors clean soil and groundwater. Optimizing reactor temperature, pH, feed amounts, and agitation optimizes microbial activity and pollutant degradation.

3.2.1 Compost-based reactors: Microorganisms in compost-based reactors transform biodegradable hazardous compounds into stablebyproducts at high temperatures. Plug-flow (vertical and horizontal) and agitated-bed reactors compost in-vessel. Microbes decomposing organic molecules boost the temperature to 122–158 °F. Anaerobic treatments handle hazardous waste, whereas aerobic composting degrades sewage sludge. Sawdust or animal manure increases medium porosity in polluted soil during in-vessel composting. Compost-based reactors need conveyors. Moisture, pH, oxygen, temperature, and the carbon-to-nitrogen ratio affect efficiency (Cookson, J. T., 1995). The municipal sewage, the soil, and the sediment in the lagoon were contaminated with compostable organic compounds. Composting is done using pentachlorophenol (PCP), sludges from refineries, and pesticides in waste from canneries, soil polluted with explosives, ethylene glycol found in sludge from landfills, and polycyclic aromatic hydrocarbons (PAHs). Composting at a high rate can take place either inside reactors or outside in the open air (Norris, R. D., 1994).

3.2.2 Slurry-based reactors: In a reactor, slurry-phase biological treatment purifies water and excavated soil. Physical characteristics, biodegradation, and soil contaminants all affect the concentration of the soil-water mélange. The reactor treats polluted soil particles and soil washwater. Depending on the biological reactor, 5–40% of the slurry's weight is composed of particles. A reactor vessel combines soil with fertiliser and oxygen. Possible treatments include microorganisms, acid, or alkali. Dewatering soil leachate after biodegradation (EPA, 1991). Slurry-phase reactors are capable of removing hydrocarbons, petrochemicals, solvents, pesticides, lumber preservatives, and other organic compounds from soils, sludges, and groundwater. Bioreactors are superior to conventional treatment methods in situations including heterogeneous soils, soils with low permeability, places where it is difficult to remove groundwater, and short treatment times (Cookson, J. T., 1995).

3.3 Land-based Treatments:

Typically, solid-phase cleaning of polluted soil necessitates ex situ remediation. The remediation of excavated waste can be accomplished through the use of mounds or cells.

3.3.1 Composting: In composting, microorganisms convert biodegradable hazardous compounds into harmless and stable byproducts at elevated temperatures. Microorganisms decompose organic waste, emitting heat in the process. Anaerobic processes manage hazardous waste, while aerobic composting breaks down sewage sediment. Composting contaminated soil employs bulking agents such as sawdust or animal manure to increase media porosity. Moisture, pH, oxygen, temperature, and the ratio of carbon to nitrogen all play important roles in the composting process (Cookson, J. T., 1995). Composting is an option for materials including pentachlorophenol (PCP), pesticides in cannery residues, explosive-contaminated soil, ethylene glycol in landfill sludges, and polycyclic aromatic hydrocarbons (PAHs) (Norris, R. D., 1994).

3.3.2 Land Farming: Farming the land is a form of bioremediation that takes place in the top soil zone, also known as "bio-treatment cells." In order to improve the quality of the soil, polluted soils, sediments, and sludges are combined with the existing soil and then thoroughly mixed. This method has effectively managed and disposed of oily sludge and other petroleum refinery byproducts for years. Near-surface hydrocarbon and pesticide contamination has been treated in situ. Land farming uses agricultural equipment. Land farming promotes hazardous chemical and microbial breakdown. The breakdown rate is slower for polycyclic aromatic hydrocarbons with more rings and larger molecular weights. More chlorinated or nitrated compounds are harder to breakdown (Hopkins, D. W., & Alexander, M., 1996).

3.4 Fungal Remediation:

Phaneorochaete chrysosporium, a white-rot fungus, may mineralize PCBs, PAHs, TNT, RDX, and HMX. White-rot fungal enzymes break down lignin and induce wood decay, deteriorating wood. In-situ bioreactors and treatments cured the white-rot fungus. White-rot fungus degrades PAHs, CAHs, polycyclic aromatics, polychlorinated biphenyls, dibenzo(p)dioxins, DDT, lindane, and some azo pigments in polluted water (Cookson, J. T., 1995). At pH 4.5 and nitrogen-limiting circumstances, PAHs such as benzo(a)pyrene, pyrene, fluorene, and phenanthrene can be decomposed. White rot and soil microbes completely mineralize tri-, tera-, and pentachlorophenol (PCP). White-rot fungus degrades cyclodiene herbicides like chlordane (Suthersan, S., 1997). White-rot fungus destroys TNT in lab-scale trials utilizing purified cultures, but factors may prevent its widespread use. Fungus and soil additives absorb TNT, while bacteria destroy it in bench-scale tests (ATTIC, 1999).

3.5 Microbial Bioremediation:

Microbial remediation of pollutants involves the use of microorganisms to degrade pollutants either completely into water and carbon dioxide (for organic pollutants) or into less toxic forms. Engineered bioreactors providing optimum conditions for microbial growth and biodegradation have been developed for use in bioremediation processes to achieve different remediation goals. Bioreactors in use range in mode of operation from batch, continuous, and fed batch bioreactors and are designed to optimize microbial processes in relation to contaminated media and the nature of pollutant. Designed bioreactors for bioremediation range from packed, stirred tanks, airlift, slurry phase, and partitioning phase reactors, among others (Tekere, M., 2019).

Out of such different technologies explained, microbial bioremediation has critical impact as it completely degrade the pollutants to water or organic pollutants. Hence, microbial technologies are effective for waste water treatment.

4. Benefits Of Microbial Bioremediation Over Other Technologies

When it comes to the bioremediation of a wide variety of pollutants found in water, air, and soil, a wide variety of microbial bioreactors have been developed and put through their paces. Additionally, a wide range of pollutants, both in terms of their physical and chemical properties, are amenable to degradation by microbes. When compared to degradation that occurs in situ in the environment under natural environmental conditions, degradation that takes place in well-developed and optimized microbial bioreactors ensures improved rates of degradation. A very diverse range of microbial species are capable of naturally degrading pollutants, and using these bioreactors ensures improved rates of degradation. The process of microbial bioremediation is an environmentally friendly and natural cleaning method that makes use of specialized pieces of cleaning equipment. This method of wastewater management removes contaminants from both the soil and the groundwater that are a result of industrial processes. Bioremediation, which involves the use of microorganisms to break down pollutants, is an efficient and cost-effective method for lowering pollution levels and maintaining clean groundwater (ESD, 2017). When compared to other technological fields. The processes involved in biology are frequently very specific. The presence of metabolically capable microbial populations, suitable environmental growth conditions, and appropriate levels of nutrients and contaminants are all important site factors required for success. When compared to other treatment options, such as microbial bioremediation, bioremediation typically requires more time. In order for bioremediation to be successful, the surrounding environment must be conducive to the growth and activity of microorganisms. This is what we mean when we talk about the environmental conditions necessary for microbial bioremediation.

5. CONCLUSION

Water contamination from organic waste, particularly hydrocarbons, pesticides, herbicides, and other harmful substances, is a worldwide problem. Utilizing microorganisms for organic pollutant biodegradation is a natural waste-reduction method that is consequently beneficial and widely recognized. For cleaning polluted water, bioremediation technologies offer significant economic, ecological, and practical benefits. Several microorganisms, especially extremophiles that can survive in adverse conditions with high pollutant concentrations, can mediate the adsorption, biodegradation, immobilization, mobilization, and/or transformation of metalloids and organic contaminants (Donati, E. R., 2019). Other processes that can be mediated include the transformation of metalloids. To accelerate the recovery of polluted places, bioaugmentation or genetically engineered microorganisms (GEM) may be used. Nonetheless, it is advised to select microorganisms with the appropriate enzymes engaged in biodegradation processes. Throughout biodegradation investigations, appropriate environmental conditions must be maintained. In this research, we have also defined about how microbial bioremediation is effective over other technologies, microbial techniques should be adopted for effective bioremediation strategies. In addition, the ever-increasing volume of data pertaining to the genomics of bacteria paves the way for novel approaches to the investigation of the genetic and molecular underpinnings of the degradation of organic pollutants.

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