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Bioremediation: An Eco-Friendly, Low-Cost Technology through Degradation of Pollutants by Microbiological Processes

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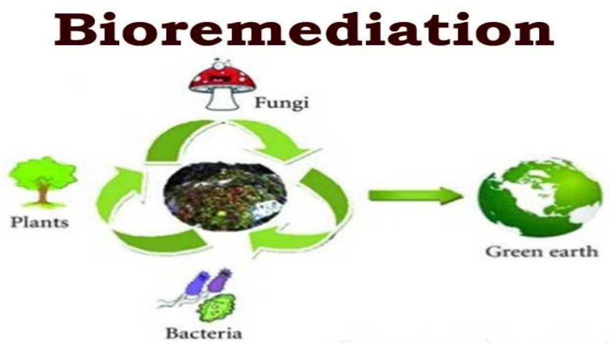
Introduction

Bioremediation is a term that refers to a group of procedures that include the use of biological systems to repair or clean up polluted environments. For bioremediation, the microbial community is constantly recorded. The majority of indigenous bacteria are capable of effectively restoring the environment by oxidising, immobilising, or converting pollutants. It tries to lower pollutant levels down to undetectable, nontoxic, or acceptable (i.e., within regulatory agency limits) levels. Bioremediation was first utilised on a significant basis in 1972, when it was used to clean up a Sun Oil pipeline accident in Ambler, Pennsylvania.

On the basis of several bioremediation case studies, the Environmental Protection Agency (EPA) created procedures for bioremediation in 1992. The hunt for a novel microorganism from polluted locations is a current bioremediation strategy. The isolated bacteria are regarded to have a high potential for pollution remediation. Genetically engineered strains and microbial consortiums have both been employed to boost the bioactivity of a bioremediant, either directly or indirectly. For the elimination of contaminants, many processes such as bioaccumulation, biodegradation routes, and distinct types of biosorption have been explored.

Principles of Bioremediation



Bioremediation is defined as the process ofbiologically degrading (mainly) organic wastesto a benign state or levels below the respectiveconcentration limits imposed by the regulatoryauthorities under controlled conditions. To putit another way, bioremediation uses livingorganisms, particularly microbes, to digestcontaminants and transform them into less hazardous orharmless forms. Bacteria, fungi, or plants that have the physiological ability to breakdown, detoxify, or render pollutants harmless are ideal species. In certain cases, the microorganisms might be native to the place (indigenous microorganisms), or they can be separated from elsewhere and introduced to the treated material (for example, bioreactors).

It goes without saying that, because bioremediation relies on microbial growth and activity, its success is significantly influenced by the environmental conditions that govern microbial growth and degradation rate. In order for the degradation process to succeed, the bioremediation approach relies on having the proper microorganisms in the right area under the right environmental circumstances. Bioremediation technology's biological processes may be improved and focused on removing certain dangerous chemicals from soil, water, or the environment. It can convert trash into water, carbon dioxide, biomass, or other non-hazardous products, obviating the need for additional treatment. A wide spectrum of chemicals can be treated via bioremediation. Apart from municipal wastes and process waters, appropriate (for each case) microorganisms can be used to degrade pesticides, industrial chemicals, crude oil components, and even compounds that were previously thought to be nonbiodegradable, such as chlorinated solvents, chlorofluorocarbons, and other synthetic organic compounds.

Bioremediation technology classification

Bioremediation technologies can be classified into two general categories: ex situ and in situ. The ex-situ techniques require the physical removal of the contaminated material and its transportation to another area for further treatment by bioreactors, land farming, or composting, whereas in situ technologies involve treatment of contaminated material in place, such as by bioventing, or bio stimulation. Most bioremediation systems work in aerobic settings, however anaerobic conditions can also be used, allowing for the destruction of resistant compounds with the help of specialised microbes. A bioremediation process' design, control, and optimised operation is a complex system of several factors, including a microbial population suitable for degrading certain pollutants, the availability of contaminants to the microorganisms, the type of soil (matrix, substrate, etc.), temperature, pH, the presence of oxygen and nutrients (primarily nitrogen and phosphorus).

Advantages of bioremediation technique

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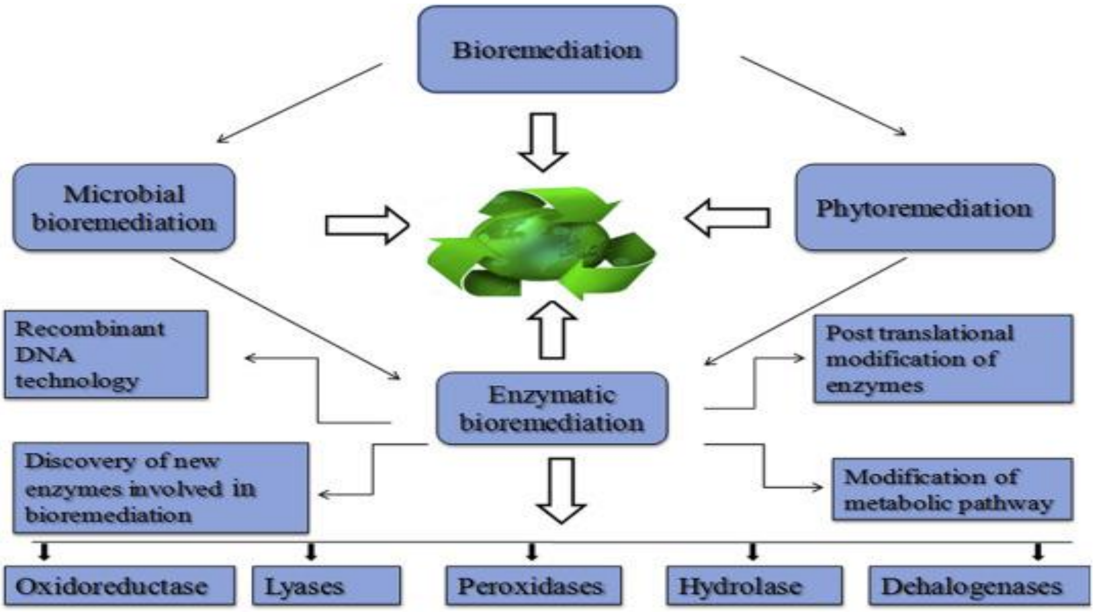
Bioremediation, as a technique, can offer several advantages over other more conventional treatment methods applicable to contaminated sites. Firstly, bioremediation, as a (more or less) natural process for the treatment of wastes, is usually acceptable by the public.



Suitable microbial populations can degrade a wide range of contaminants, rendering (transforming) a hazardous compound to a harmless one. Eventually, the residues of the treatment may include simpler compounds, such as carbon dioxide or water, but also cell biomass. Therefore, a chance for future hazards in the treatment and disposal of contaminated material is practically eliminated. Often, bioremediation can be performed *on-site*, thus reducing the associated transportation costs and liabilities, and also the potential threats to human health and to the environment due to the transportation of hazardous materials. In addition, it is often applied as in situ technology hence the site disruption is minimized, enabling the above ground activities to be continued. Needless to say, that bioremediation as a biological system can often be shown to be less expensive than other relevant treatment technologies, which can be applied for the same purpose. Finally, bioremediation can be combined with other technologies into a process chain, thus increasing the efficiency of the whole treatment.

Disadvantages of Bioremediation

Bioremediation, like any other technology, has certain disadvantages.It is specifically confined to biodegradable chemicals. There are also growing fears that bioremediation

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products will be more persistent or dangerous than the parent substances. Trichloroethylene (TCE) is transformed to vinyl chloride, a recognised carcinogen, by a sequence of biological processes that result in the elimination of chlorine atoms in a sequential manner. Reductive dehalogenation is the name for this procedure. Furthermore, the efficiency of bioremediation is greatly dependent on microbial development and other site-specific environmental factors. Finally, bioremediation takes longer than alternative treatment methods like incineration or soil excavation and removal.

Limitations of biodegradation

Bioremediation, which uses microorganisms to remove pollutants, is a promising technology that is both cost-effective and efficient. Current bioremediation systems, on the other hand, have a number of drawbacks, including poorer bioavailability of pollutants on temporal and geographical dimensions, low microorganism efficiency in the region, and a lack of benchmark values for bioremediation testing in the field. Suitable environmental conditions for microbial development, the existence of metabolically active microbial populations, and appropriate nutrition and pollutant levels are all variables that impact biodegradation. Monoculture strains are capable of degrading organic contaminants effectively. However, microbial consortia and combining bacteria with fungi may efficiently degrade PAHs and volatile organic compounds. Moreover, not all compounds can be rapidly and completely degraded; thus, bioremediation is limited to biodegradable compounds.

Conclusion

Bioremediation is a new technique that may be used in conjunction with existing physical and chemical treatment methods to effectively control a wide range of contaminants in the environment. It appears to be a long-term method to environmental pollution control, thus further research is needed in this field. Environmental impact on the fate and behaviour of environmental contaminants, as well as the selection and performance of the most appropriate bioremediation technique and another relevant technique that can sustain the effective and successful operation and monitoring of a bioremediation process, must all be considered. With specific optimum circumstances, vermi-biofiltration and genetic engineering technologies may be promoted and adopted at bigger sizes for sustainable waste recycling, contaminated soil remediation, solid waste management, and so on. Future rules will be guided by ongoing research and development initiatives, which will address bioremediation objectives, pollutant availability, and their potential danger to natural ecosystems and human health. Furthermore, transdisciplinary technologies would make it easier to predict the availability and biodegradation of contaminants in any natural or man-made system, as well as the degree of damage to human health posed by diverse environmental pollutants.