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Review on Bioremediation of Polluted Environment: A Management Tool

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ABSTRACT

The term bioremediation has been introduced to describe the process of using biological agents to remove toxic waste from environment. Bioremediation is the most effective management tool to manage the polluted environment and recover contaminated soil. Bioremediation is an attractive and successful cleaning technique for polluted environment. Bioremediation has been used at a number of sites worldwide, including Europe, with varying degrees of success. Bioremediation, both in situ and ex situ have also enjoyed strong scientific growth, in part due to the increased use of natural attenuation, since most natural attenuation is due to biodegradation. Bioremediation and natural attenuation are also seen as a solution for emerging contaminant problems, e.g. endocrine disrupters, landfill stabilization, mixed waste biotreatment and biological carbon sequestration. Microbes are very helpful to remediate the contaminated environment. Number of microbes including aerobes, anaerobes and fungi are involved in bioremediation process.

Keywords: Bioremediation, Biotechnology, Microbes, Carbon Squestration.

1. Introduction

Intensification of agriculture and manufacturing industries has resulted in increased release of a wide range of xenobiotic compounds to the environment. Excess loading of hazardous waste has led to scarcity of clean water and disturbances of soil thus limiting crop production (Kamaludeen et al., 2003). Bioremediation uses biological agents, mainly microorganisms i.e. yeast, fungi or bacteria to clean up contaminated soil and water (Strong and Burgess, 2008). This technology relies on promoting the growth of specific microflora or microbial consortia that are indigenous to the contaminated sites that are able to perform desired activities (Agarwal, 1998). Establishment of such microbial consortia can be done in several ways e.g. by promoting growth through addition of nutrients, by adding terminal electron acceptor or by controlling moisture and temperature conditions (Hess et al., 1997; Agarwal, 1998; Smith et al., 1998). In bioremediation processes, microorganisms use the contaminants as nutrient or energy sources (Hess et al., 1997; Agarwal, 1998; Tang et al., 2007).

The population explosion in the world has resulted in an increase in the area of polluted soil and water. As the number of people continues increasing day by day it also brings with it a growing pressure on our natural resources i.e. air, water and land resources. In order to outfit to the demands of the people, the rapid expansion of industries, food, health care, vehicles, etc. is necessary. But it is very difficult to maintain the quality of

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life with all these new developments, which are unfavorable to the environment in which we live, if proper management is not applied. In nature there are various fungi, bacteria and microorganisms that are constantly at work to break down organic compounds but the question arises when pollution occurs, who will do this clean up job? Since the quality of life is inextricably linked to the overall quality of the environment, global attention has been focused on ways to sustain and preserve the environment. This endeavor is possible by involving biotechnology. The types of contaminants that Environmental Biotechnology investigators have expertise with include chlorinated solvents, petroleum hydrocarbons, polynuclear aromatic hydrocarbons, ketones, TNT, inorganic nitrogen (NO_3, NH_4), Tt, , Pu, Np, Cr, U and other heavy metals. Bioremediation is the term used to describe biological strategies applicable to repair of damaged environment using biological factors. In the case of oil spills, the process exploits the catabolic ability of microorganism feeding on oil. Several workers (Odu, 1978; Sloan, 1987; Ijah and Antai, 1988; Okpokwasili and Okorie, 1988; Barnhart and Meyers, 1989; Anon, 1990; Pritchard, 1991; Pritchard and Costa, 1991; Hoyle, 1992; Ijah, 2002 and Ijah, 2003) have described various application of microorganism in the bioremediation of oil pollution with encouraging results.

The bioremediation and natural attenuation area has both basic research and field application foci for the environmental biotechnology. The basic research foci are co-metabolism, biotreatability, biotransformation kinetics, and modeling of biogeochemical processes. The field application foci are co-metabolic techniques, biogeochemical assessment techniques, and modeling of attenuation and environmental fate (Kumar et al 2010). Bioremediation can be defined as any process that uses microorganisms or their enzymes to return the environment altered by contaminants to its original condition. Bioremediation may be employed in order to attack specific contaminants, such as chlorinated pesticides that are degraded by bacteria, or a more general approach may be taken, such as oil spills that are broken down using multiple techniques including the addition of fertilizer to facilitate the decomposition of crude oil by bacteria. Not all contaminants are readily treated through the use of bioremediation; heavy metals such as cadmium and lead are not readily absorbed or captured by organisms (Vidali 2001). The integration of metals such as mercury into the food chain may make things worse as organism bioaccumulate these metals. However, there are a number of advantages to bioremediation, which may be employed in areas which cannot be reached easily without excavation. The foundation of bioremediation has been the natural ability of microorganisms to degrade organic compounds. Bioremediation is not a panacea but rather a natural process alternative to such methods as incineration, catalytic destruction, the use of adsorbents, and the physical removal and subsequent destruction of pollutants. The cost of moving and incinerating pollutants is at least ten times that of in situ biological treatment. By integrating proper utilization of natural or modified microbial capabilities with appropriate engineering designs to provide suitable growth environments, bioremediation can be successful in the field. However, a gap exists between advances in laboratory research and commercial field applications. Two major factors responsible for this gap are the lack of a sufficient knowledge base to accurately predict pollutant degradation rates and fates and sites designated as field research centers for bioremediation research and technology demonstrations. Laboratory and microcosm studies have documented the potential use of microorganisms for bioremediation. However, the physiologic potential of microbial populations to remediate environments of relevant size, heterogeneity and variability has not been adequately tested. Successful application of bioremediation techniques must address both the heterogeneous nature of many contaminated waste sites and the complexity of using living organisms. There has been progress in overcoming some of the barriers that have impeded bioremediation from being successfully applied in the field. Scientists have to put their efforts to search for organisms with better biodegradation kinetics for a variety of contaminants within broad environmental habitats. Studies examining extremophiles could result in using organisms in situ that have a high tolerance for organic solvents and alkaline soils or waters and that function at high temperatures for more efficient ex situ activity in bioreactors.

1.1 Biotechnology in Pollution Management

Biotechnology can be applied to assess the well being of ecosystems, transform pollutants into benign substances, generate biodegradable materials from renewable sources and develop environmentally safe manufacturing and disposal processes. Biotechnology utilizes the application of genetic engineering to improve the efficiency and cost, which are key factors in the future widespread exploitation of microorganisms to reduce the environmental burden of toxic substances. Keeping in view of the urgent need of a most efficient environmental biotechnological process, researchers have devised a technique called bioremediation, which is an emerging approach to rehabilitating areas contaminated by pollutants or otherwise damaged through ecosystem mismanagement. Bioremediation applies living microorganisms to degrade environmental pollutants or to prevent pollution or it is a technology for removing pollutants from the environment thus restoring the original natural surroundings and preventing further pollution. The rapid expansion and increasing sophistication of the chemical industries in the last century has meant that there has been increasing levels of complex toxic effluents being released into the environment (Vidali 2001). Many major incidents have occurred in the past which reveal the necessity to prevent the escape of effluents into the environment, such as the Exxon Valdez oil spill, the Union-Carbide (Dow) Bhopal disaster, large-scale contamination of the Rhine River, the progressive deterioration of the aquatic habitats and conifer forests in the Northeastern US, Canada and parts of Europe, or the release of radioactive material in the Chernobyl accident, etc. The conventional techniques used for remediation have been to dig up contaminated site and remove it to a landfill, or to cap and contain the contaminated areas of a site. The methods have some drawbacks. The first method simply moves the contamination elsewhere and may create significant risks in the excavation, handling, and transport of hazardous material. Additionally, it is very difficult and increasingly expensive to find new landfill sites for the final disposal of the material. The cap and contain method is only an interim solution since the contamination remains on site, requiring monitoring and maintenance of the isolation barriers long into the future, with all the associated costs and potential liability. A better approach than these traditional methods is to completely destroy the pollutants if possible, or at least to transform them to innocuous substances. Some technologies that have been used are high-temperature incineration and various types of chemical decomposition. Bioremediation is an option that offers the possibility to destroy or render harmless various contaminants using natural biological activity (Gupta 2003). As such, it uses relatively low-cost, low-technology techniques, which generally have a high public acceptance and can often be carried out on site. It will not always be suitable, however, as the range of contaminants on which it is effective is limited, the time scales involved are relatively long and the residual contaminant levels achievable may not always be appropriate. Although the methodologies employed are not technically complex, considerable experience and expertise may be required to design and implement a successful bioremediation program, due to the need to thoroughly assess a site for suitability and to optimize conditions to achieve a satisfactory result. Because bioremediation give the impression a good alternative to conventional clean-up technologies research in this field. Bioremediation has been used at a number of sites worldwide, including Europe, with varying degrees of success. Techniques are improving as greater knowledge and experience are gained and there is no doubt that bioremediation has great potential for dealing with certain types of site contamination. Unfortunately, the principles, techniques, advantages and disadvantages of bioremediation are not widely known or understood, especially among those who will have to deal directly with bioremediation proposals, such as site owners and regulators.

2. Principles of Bioremediation

Recent studies in molecular biology and ecology offers numerous opportunities for more efficient biological processes. Notable accomplishments of these studies include the clean-up of polluted water and land areas. Bioremediation is defined as the process whereby organic wastes are biologically degraded under controlled conditions to an innocuous state, or to levels below concentration limits established by regulatory authorities (Mueller 1996). By definition, bioremediation is the use of living organisms, primarily microorganisms, to degrade the environmental contaminants into less toxic forms. It uses naturally occurring bacteria and fungi or plants to degrade or detoxify substances hazardous to human health and/or the environment. The microorganisms may be indigenous to a contaminated area or they may be isolated from elsewhere and brought to the contaminated site. Contaminant compounds are transformed by living organisms through reactions that take place as a part of their metabolic processes. Biodegradation of a compound is often a result of the actions of multiple organisms. When microorganisms are imported to a contaminated site to enhance degradation we have a process known as bioaugmentation. For bioremediation to be effective, microorganisms must enzymatically attack the pollutants and convert them to harmless products (Vidali 2001). As bioremediation can be effective only where environmental conditions permit microbial growth and activity, its application often involves the manipulation of environmental parameters to allow microbial growth and degradation to proceed at a faster rate. Like other technologies, bioremediation has its limitations. Some contaminants, such as chlorinated organic or high aromatic hydrocarbons, are resistant to microbial attack. They are degraded either slowly or not at all, hence it is not easy to predict the rates of clean-up for a bioremediation exercise; there are no rules to predict if a contaminant can be degraded. Bioremediation techniques are typically more economical than traditional methods such as incineration, and some pollutants can be treated on site, thus reducing exposure risks for clean-up personnel, or potentially wider exposure as a result of transportation accidents. Since bioremediation is based on natural attenuation the public considers it more acceptable than other technologies. Most bioremediation systems are run under aerobic conditions, but running a system under anaerobic conditions (Colberg and Young 1995) may permit microbial organisms to degrade otherwise recalcitrant molecules.

2.1 Microbial Populations for Bioremediation Processes

Microorganisms can be isolated from almost any environmental conditions. Microbes can adapt and grow at subzero temperatures, as well as extreme heat, desert conditions, in water, with an excess of oxygen and in anaerobic conditions, with the presence of hazardous compounds or on any waste stream. The main requirements are an energy source and a carbon source (Vidali 2001). Because of the adaptability of microbes and other biological systems, these can be used to degrade or remediate environmental hazards. Natural organisms, either indigenous or extraneous (introduced), are the prime agents used for bioremediation (Prescott et al., 2002). The organisms that are utilized vary, depending on the chemical nature of the polluting agents, and are to be selected carefully as they only survive within a limited range of chemical contaminants (Prescott et al., 2002; Dubey, 2004). Since numerous types of pollutants are to be encountered in a contaminated site, diverse types of microorganisms are likely to be required for effective mediation (Table 1 and 2 ; Watanabe et al., 2001). The first patent for a biological remediation agent was registered in 1974, being a strain of *Pseudomonas putida* (Prescott et al., 2002) that was able to degrade petroleum. In 1991, about 70 microbial genera were reported to degrade petroleum compounds (U.S Congress, 1991) and almost an equal number has been added to the list in the successive two decades (Glazer and Nikaido, 2007).

2.2 Some groups of microbes

1. Aerobic: Examples of aerobic bacteria recognized for their degradative abilities are *Pseudomonas, Alcaligenes, Sphingomonas, Rhodococcus,* and *Mycobacterium.* These microbes have often been reported to degrade pesticides and hydrocarbons, both alkanes and polyaromatic compounds. Many of these bacteria use the contaminant as the sole source of carbon and energy.

2. Anaerobic. Anaerobic bacteria are not as frequently used as aerobic bacteria. There is an increasing interest in anaerobic bacteria used for bioremediation of polychlorinated biphenyls (PCBs) in river sediments, dechlorination of the solvent trichloroethylene (TCE) and chloroform.

3. Ligninolytic fungi. Fungi such as the white rot fungus *Phanaerochaete chrysosporium* have the ability to degrade an extremely diverse range of persistent or toxic environmental pollutants. Common substrates used include straw, saw dust, or corn cobs.

4. Methylotrophs. Aerobic bacteria that grow utilizing methane for carbon and energy. The initial enzyme in the pathway for aerobic degradation, methane monooxygenase, has a broad substrate range and is active against a wide range of compounds, including the chlorinated aliphatic trichloroethylene and 1, 2-dichloroethane.

For degradation it is necessary that bacteria and the contaminants must be in contact. This is not easily achieved, as neither the microbes nor contaminants are uniformly spread in the soil. Some bacteria are mobile and exhibit a chemotactic response, sensing the contaminant and moving toward it. Other microbes such as fungi grow in a filamentous form toward the contaminant. Many different types of organisms such as plants can be used for bioremediation but microorganisms show the greatest potential. Microorganisms primarily bacteria and fungi are nature's original recyclers. Their capability to transform natural and synthetic chemicals into sources of energy and raw materials for their own growth suggests that expensive chemical or physical remediation processes might be replaced with biological processes that are lower in cost and more environmentally friendly. Therefore, microorganisms represent a promising, largely untapped resource for new environmental biotechnologies. Research continues to verify the bioremediation potential of microorganisms. For instance, a recent addition to the growing list of bacteria that can reduce metals is *Geobacter metallireducens,* which removes uranium, a radioactive waste; from drainage waters in mining operations and from contaminated groundwater. Even dead microbial cells can be useful in bioremediation technologies. These discoveries suggest that further exploration of microbial diversity is likely to lead to the discovery of many more organisms with unique properties useful in bioremediation (U.S. EPA Seminars 1996). Application of microorganisms is not limited to one field of study of bioremediation, it has an extensive use; Petroleum, its products and oils constitute hydrocarbons and if present in the environment causes pollution. Oil slicks caused by oil tankers and petrol leakage into the marine environment are now a constantly occurring phenomenon. Several microorganisms can utilize oil as a source of food, and many of them produce potent surface-active compounds that can emulsify oil in water and facilitate its removal. Unlike chemical surfactants, the microbial emulsifier is non-toxic and biodegradable. The microorganisms capable of degrading petroleum include pseudomonads, various corynebacteria, mycobacteria and some yeast (Mueller 1996). Apart from degrading hydrocarbons, microbes also have the ability to remove industrial wastes, reduce the toxic cations of heavy metals to a much less toxic soluble form. For instance, plants like locoweed remove large amounts of the toxic element selenium. The selenium is stored in plant tissues where it poses no harm until and unless the plant is eaten. Many algae and bacteria produce secretions that attract metals that are toxic in high levels. The metals are in effect removed from the food chain by being bound to the secretions. Degradation of dyes is also brought about by some anaerobic bacteria and fungi (Colberg 1995). To boost the world's food production rate to compensate for the increasing population, pesticides are being used. The extensive use of these artificial boosters has lead to the accumulation of artificial complex compounds called xenobiotics. By introducing genetically altered microbes, it is possible to degrade these compounds.

3. Types of Bioremediation

On the basis of removal and transportation of wastes for treatment there are basically two methods-

1. In situ bioremediation
2. Ex situ bioremediation

3.1 In Situ Bioremediation

In situ bioremediation means there is no need to excavate or remove soils or water in order to accomplish remediation. In situ biodegradation involves supplying oxygen and nutrients by circulating aqueous solutions through contaminated soils to stimulate naturally occurring bacteria to degrade organic contaminants. It can be used for soil and groundwater. Generally, this technique includes conditions such as the infiltration of water-containing nutrients and oxygen or other electron acceptors for groundwater treatment (Vidali 2001). Most often, in situ bioremediation is applied to the degradation of contaminants in saturated soils and groundwater. It is a superior method to cleaning contaminated environments since it is cheaper and uses harmless microbial organisms to degrade the chemicals. Chemotaxis is important to the study of in-situ bioremediation because microbial organisms with chemotactic abilities can move into an area containing contaminants. So by enhancing the cells' chemotactic abilities, in- situ bioremediation will become a safer method in degrading harmful compounds.

3.2 Types of In Situ Bioremediation

3.2.1 Intrinsic bioremediation

This approach deals with stimulation of indigenous or naturally occurring microbial populations by feeding them nutrients and oxygen to increase their metabolic activity.

3.2.2 Engineered in situ bioremediation

The second approach involves the introduction of certain microorganisms to the site of contamination. When site conditions are not suitable, engineered systems have to be introduced to that particular site. Engineered in situ bioremediation accelerates the degradation process by enhancing the physico-chemical conditions to encourage the growth of microorganisms. Oxygen, electron acceptors and nutrients (nitrogen and phosphorus) promote microbial growth. Advantage and Disadvantage of In situ Bioremediation: This method have many potential advantages as it does not require excavation of the contaminated soil and hence proves to be cost effective, there is minimal site disruption, so the amount of dust created is less and simultaneous treatment of soil and groundwater is possible. It poses some disadvantages also as the method is time consuming compared to the other remedial methods, seasonal variation of the microbial activity due to direct exposure to changes in environmental factors that cannot be controlled and problematic application of treatment additives. Microorganisms act well only when the waste materials present allow them to produce nutrients and energy for the development of more cells. When these conditions are not favorable then their capacity to degrade is reduced. In such cases genetically engineered microorganisms have to be used, although stimulating indigenous microorganisms is preferred.

3.3 Ex Situ Bioremediation

This process requires excavation of contaminated soil or pumping of groundwater to facilitate microbial degradation. This technique has more disadvantages than advantages. Ex situ bioremediation techniques involve the excavation or removal of contaminated soil from ground.

Depending on the state of the contaminant to be removed, ex situ bioremediation is classified as:

1. Solid phase system (including land treatment and soil piles)
2. Slurry phase systems (including solid- liquid suspensions in bioreactors)

Solid phase treatment: - It includes organic wastes (leaves, animal manures and agricultural wastes) and problematic wastes e.g. domestic and industrial wastes, sewage sludge and municipal solid wastes. Solid-phase soil treatment processes include landfarming, soil biopiles, and composting.

1. Land farming: It is a simple technique in which contaminated soil is excavated and spread over a pre-pared bed and periodically tilled until pollutants are degraded. The goal is to stimulate indigenous biodegradative microorganisms and facilitate their aerobic degradation of contaminants. In general, the practice is limited to the treatment of superficial 10–35 cm of soil. Since land farming has the potential to reduce monitoring and maintenance costs, as well as clean-up liabilities, it has received much attention as a disposal alternative.

2. Composting: Composting is a technique that involves combining contaminated soil with nonhazardous organic amendants such as manure or agricultural wastes. The presence of these organic materials supports the development of a rich microbial population and elevated temperature characteristic of composting.

3. Biopiles: Biopiles are a hybrid of land farming and composting. Essentially, engineered cells are constructed as aerated composted piles. Typically used for treatment of surface contamination with petroleum hydrocarbons they are a refined version of land farming that tend to control physical losses of the contaminants by leaching and volatilization. Biopiles provide a favorable environment for indigenous aerobic and anaerobic microorganisms (U.S. EPA handbook).

Slurry-Phase Bioremediation: - Slurry phase bioremediation is a relatively more rapid process compared to the other treatment processes. Contaminated soil is combined with water and other additives in a large tank called a bioreactor and mixed to keep the microorganisms, which are already present in the soil, in contact with the contaminants in the soil. Nutrients and oxygen are added and conditions in the bioreactor are controlled to create the optimum environment for the microorganisms to degrade the contaminants. When the treatment is completed, the water is removed from the solids, which are disposed of or treated further if they still contain pollutants.

1. Bioreactors: Slurry reactors or aqueous reactors are used for ex situ treatment of contaminated soil and water pumped up from a contaminated plume. Bioremediation in reactors involves the processing of contaminated solid material e.g. soil, sediment, sludge or water through an engineered containment system. A slurry bioreactor may be defined as a containment vessel and apparatus used to create a three-phase e.g. solid, liquid, and gas, mixing condition to increase the bioremediation rate of soil-bound and water-soluble pollutants as a water slurry of the contaminated soil and biomass capable of degrading target contaminants. In general, the rate and extent of biodegradation are greater in a bioreactor system than in situ or in solid-phase systems because the contained environment is more manageable and hence more controllable and predictable. Despite the advantages of reactor systems, there are some disadvantages. The contaminated soil requires pre treatment or alternatively the contaminant can be stripped from the soil via soil washing or physical extraction before being placed in a bioreactor (U.S. EPA Handbook).

2. Bioventing: It is the most common in situ treatment and involves supplying air and nutrients through wells to contaminated soil to stimulate the indigenous bacteria. Bioventing employs low air flow rates and provides only the amount of oxygen necessary for the biodegradation while minimizing volatilization and release of contaminants to the atmosphere. It works for simple hydrocarbons and can be used where the contamination is deep under the surface.

3. Biosparging: Biosparging involves the injection of air under pressure below the water table to increase groundwater oxygen concentrations and enhance the rate of biological degradation of contaminants by naturally occurring bacteria. Biosparging increases the mixing in the saturated zone and there-by increases the contact between soil and groundwater. The ease and low cost of installing small-diameter air injection points allows considerable flexibility in the design and construction of the system.

4. Bioaugmentation: Bioremediation frequently involves the addition of microorganisms indigenous or exogenous to the contaminated sites. Two factors limit the use of added microbial cultures in a land treatment unit: no indigenous cultures rarely compete well enough with an indigenous population to develop and sustain useful population levels and most soils with long-term exposure to biodegradable waste have indigenous microorganisms that are effective degrades if the land treatment unit is well managed.

3.4 Advantages of Bioremediation

1. Bioremediation is a natural process and is therefore perceived by the public as an acceptable waste treatment process for contaminated material such as soil. Microbes able to degrade the contaminant increase in numbers when the contaminant is present; when the contaminant is degraded, the biodegradative population declines. The residues for the treatment are usually harmless products and include carbon dioxide, water, and cell biomass.

2. Theoretically, bioremediation is useful for the complete destruction of a wide variety of contaminants. Many compounds that are legally considered to be hazardous can be transformed to harmless products. This eliminates the chance of future liability associated with treatment and disposal of contaminated material.

3. Instead of transferring contaminants from one environmental medium to another, for example, from land to water or air, the complete destruction of target pollutants is possible.

4. Bioremediation can often be carried out on site, often without causing a major disruption of normal activities. This also eliminates the need to transport quantities of waste off site and the potential threats to human health and the environment that can arise during transportation.

5. Bioremediation can prove less expensive than other technologies that are used for clean-up of hazardous waste.

3.5 Disadvantages Of Bioremediation

Bioremediation, although considered a boon in the midst of present day environmental situations, can also be considered problematic because, while additives are added to enhance the functioning of one particular bacterium, fungi or any other microorganisms, it may be disruptive to other organisms inhabiting that same environment when done in situ (Vidali 2001). Even if genetically modified microorganisms are released into the environment after a certain point of time it becomes difficult to remove them. Bioremediation is generally very costly, is labor intensive, and can take several months for the remediation to achieve acceptable levels. Another problem regarding the use of in situ and ex situ processes is that it is capable of causing far more damage than the actual pollution itself.

1. Bioremediation is limited to those compounds that are biodegradable. Not all compounds are susceptible to rapid and complete degradation.
2. There are some concerns that the products of biodegradation may be more persistent or toxic than the parent compound.
3. Biological processes are often highly specific. Important site factors required for success include the presence of metabolically capable microbial populations, suitable environmental growth conditions, and appropriate levels of nutrients and contaminants.
4. It is difficult to extrapolate from bench and pilot-scale studies to full-scale field operations.

5. Research is needed to develop and engineer bioremediation technologies that are appropriate for sites with complex mixtures of contaminants that are not evenly dispersed in the environment.
6. Contaminants may be present as solids, liquids and gases.
7. Bioremediation often takes longer than other treatment options, such as excavation and removal of soil or incineration.

Regulatory uncertainty remains regarding acceptable performance criteria for bioremediation. There is no accepted definition of clean, evaluating performance of bioremediation is difficult and there are no acceptable endpoints for bioremediation treatments. Bioremediation is not effective only for the degradation of pollutants but it can also be used to clean unwanted substances from air, soil, water and raw materials form industrial waste. With this in view, though many engineered processes for applying bioremediation have been developed but the inexpensive treatment of such sites has remained an elusive goal (Zeyaullah et al 2009).

Table 1: Microorganisms having biodegradation potential for xenobiotics.

Organism	**Toxic chemicals**	**Reference**
Pseudomonas	Benzene, anthracene, hydrocarbons,	Kapley *et al.,* 1999;
spp	PCBs	Cybulski *et al,* 2003
	Halogenated hydrocarbons, linear	Lal and Khanna,
Alcaligenes spp	alkylbenzene sulfonates, polycyclic	1996
	aromatics, PCBs	
	Benzene,hydrocarbons,pentachlorop	
Arthrobacter	henol, phenoxyacetate, polycyclic	Jogdand, 1995
spp	aromatic	
	Aromatics, long chain alkanes,	
	phenol, cresol	Cybulski *et al.,*
Bacillus spp	Halogenated hydrocarbons,	2003
	phenoxyacetates	
Corynebacteriu		Jogdand, 1995
m spp	Aromatics	
	Aromatics	
Flavobacterium	Naphthalene, biphenyl	Jogdand, 1995
spp	Aromatics, branched hydrocarbons	Jogdand, 1995
Azotobacter	benzene,cycloparaffins	Dean-Ross *et al.,*
spp	Hydrocarbons	2002
Rhodococcus	Aromatics	Sunggyu, 1995
spp	Aromatics	
Mycobacterium	Hydrocarbons, polycyclic	Park *et al.,* 1998
spp	hydrocarbons	Jogdand, 1995
	Phenoxyacetate, halogenated	Jogdand, 1995
Nocardia spp	hydrocarbon diazinon	Jogdand, 1995;
Methosinus sp	PCBs, formaldehyde	Ijah, 1998
Met hanogens	PCBs, polycyclic aromatics,	
Xanthomonas	biphenyls	Jogdand, 1995
spp		

Table 2: Microbes utilize the heavy metals:

Microorganism	Elements	References
Bacillus spp. *Pseudomonas aeruginosa* *Zooglea spp.* *Citrobacter spp.* *Chlorella vulgaris* *Aspergilus niger* *Pleurotus ostreatus* *Rhizopus arrhizus* *Stereum hirsutum* *Phormidium valderium* *Ganoderma applantus* *Volvariella*	Cu, Zn U, Cu, Ni Co, Ni, Cd Cd, U, Pb Au, Cu, Ni, U, Pb, Hg, Zn Cd, Zn Zn, Ag, Th, U Cd, Cu, Zn Ag, Hg, P Cd, Pb, Ca Cd, Co, Cu, Ni Cd, Pb Cu, Hg, Pb Zn, Pb, Cu	Philip *et al.,* 2000; Gunasekaran *et al.,* 2003 Sar *et al.,* 1999; Sar and D'Souza, 2001 Gunasekaran *et al.,* 2003 Yan and Viraraghavan, 2001; Gunasekaran *et al.,* 2003 Pearson, 1969; Gunasekaran *et al.,* 2003 Guibal *et al.,* 1995; Gunasekaran *et al.,* 2003 Favero *et al.,* 1991 Gunasekaran *et al.,* 2003 Gabriel *et al.,* 1994 and1 996 Gabriel *et al.,* 1994 and 1996 Gabriel *et al.,* 1994 and 1996 Purkayastha &

4. Conclusion

Bioremediation provides a technique for cleaning up pollution by enhancing the natural biodegradation processes. So by developing an understanding of microbial communities and their response to the natural environment and pollutants, expanding the knowledge of the genetics of the microbes to increase capabilities to degrade pollutants, conducting field trials of new bioremediation techniques which are cost effective, and dedicating sites which are set aside for long term research purpose, these opportunities offer potential for significant advances. There is no doubt that bioremediation is in the process of paving a way to greener pastures. Regardless of which aspect of bioremediation that is used, this technology offers an efficient and cost effective way to treat contaminated ground water and soil. Its advantages generally outweigh the disadvantages, which is evident by the number of sites that choose to use this technology and its increasing popularity. Once again thanks to the bioremediation technology to clean up the polluted environment and therefore may be used as management tool.

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