Bioremediation of Contaminated Water-Based on Various Technologies

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Significance and Impact of the Study

Bioremediation as a biological technology has the relatively low-cost, low-pollution techniques, which generally have a high public acceptance and can be carried out on sites. Bioremediation has been used in large numbers of countries worldwide. There is no doubt that bioremediation has the great potential for dealing with certain types of site contamination. However, the principles, techniques, advantages, and disadvantages of bioremediation using in different contaminated water are not widely known or understood, especially among those who will have to deal directly with bioremediation proposals, such as site owners and regulators. Here, I intended to assist by providing a straightforward, practical view of the processes involved in bioremediation, the features and the issues to be considered.

Abstract

This paper presents a brief outline of the development of bioremediation technologies (Microorganism remediation, phytoremediation, animal remediation and other methods applied in bioremediation.) applied at heavy metals, eutrophication, petroleum spills, pesticide contamination and other organic pollutions in water. Ecological relationships of microorganisms and contaminates were clearly expressed here. And mechanisms and types (Phytoextraction, phytodegradation, rhizofiltration, phytostabilization, phytovolatilization) of phytoremediation were fully discussed followed by animal remediation, which was not a popular way of bioremediation for contamination. As for other ways of bioremediation, such as addition of nutrient activators or surfactants, precipitation, ion exchange et al was not a economical method, and cannot be utilized widely. The main impact factors (e.g. biological factors, environmental factors, pollutants), major advantages and disadvantages of bioremediation are discussed. Numerous natural and man-caused factors, especially the evolution of human industrial civilization and rapid progress of modern life, have polluted abundant water resources. Lots of compounds that are considered to be hazardous legally can be degraded by bioremediation. Residues of the treatment are usually harmless products to environment. Bioremediation can be proved less expensive than other technologies to clean contaminants. It also eliminates the potential threats to human health and environment. In short, here an overview of the recent status and potential areas of applications are sketched in this paper.

Keywords: Contaminated Water, Bioremediation, Phytoremediation, Animal Remediation, Heavy Metals, Eutrophication, Petroleum Spills, Pesticide Contamination, Organic Pollution, Microorganism

OALib PrePrints | http://dx.doi.org/10.4236/oalib.preprints.1200056 |
Received: 2014/07/19, published: 2014/07/31

1. Introduction

The quality of human life on Earth is inextricably linked to the overall quality of water resources. It has been estimated that a minimum of 7.5 liters of water per person per day is required in the home for drinking, preparing food, and personal hygiene; at least 50 liters per person per day is needed to ensure all personal hygiene, food hygiene, domestic cleaning, and laundry needs [1]. This domestic water consumption is dwarfed by the demands of agriculture and ecosystems, even in wealthy countries where per capita domestic water consumption greatly exceeds these figures [2]. In early times, we believed that we had an unlimited abundance of water resources. Today, however, the resources in the world show, in greater or lesser degree, our carelessness and negligence in using them. Increases in environmental contamination lead to a progressive deterioration of environmental quality. This condition challenges our global society to find effective measures of remediation to reverse the negative conditions that severely threaten human and environmental health connected with the production, use, and disposal of hazardous substances were less well recognized. This is a worldwide problem, and the estimated number of contaminated sites is significant [3]. Excess loading of hazardous waste has led to scarcity of clean water and disturbances of soil thus limiting crop production [4].

Study results of the extra and intramural research programs of the National Institute of Environmental Health Sciences have contributed to the increasing public awareness that human diseases often have preventable environmental components. Pollution prevention and environmental remediation are interwoven into all strategies proposed for sustaining human and environmental health. The conventional techniques used for remediation have been to transfer contaminated water, move the contamination elsewhere and may create significant risks in the other water body, handling, and transport of hazardous material. Additionally, it is very difficult and increasingly expensive to find new landfill sites for removing the final disposal of the material.

Compared to other methods, bioremediation is a more promising and less expensive way for cleaning up contaminated water and some soil [5, 6]. Bioremediation uses biological agents, mainly microorganisms, e.g. yeast, fungi or bacteria to clean up contaminated water [7]. Microbes play an essential role in natural cycles and they are the primary stimulant in bioremediation of contaminated environments [8-12]. Establishment of microbial groups 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, among others [13-15]. In bioremediation processes, microorganisms use the contaminants as nutrient or energy sources [16]. Bioremediation uses relatively low-cost, low-technology techniques, which generally have a high public acceptance and can be carried out on sites. However, as the range of contaminants on which the effect is limited, the time scales involved are relatively long, and the residual contaminant levels achievable may not always be appropriate. Due to the need to thoroughly assess a site for suitability and to optimize conditions to achieve a satisfactory result, considerable experience and expertise may be required to design and implement a successful bioremediation program.

Bioremediation has been used in numbers of sites worldwide, including Europe and North America, with varying degrees of success. There is no doubt that bioremediation has the great potential for dealing with certain types of site contamination. However, the principles, techniques, advantages, and disadvantages of bioremediation using in different contaminated water are not widely known or understood, especially among those who will have to deal directly with bioremediation proposals,

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Received: 2014/07/19, published: 2014/07/31

such as site owners and regulators. Here, I intended to assist by providing a straightforward, practical view of the processes involved in bioremediation, the features and the issues to be considered.

2. Principles or Bioremediation

Bioremediation is defined as the process whereby organic wastes are biologically degraded under controlled conditions to an innocuous state, or to levels below limited concentration established by regulatory authorities [17].

The principle of bioremediation primarily comes from the control of microorganism in contaminated environment, generally it means microorganism remediation. Then following by the development of environmental biotechnology, the role of phytoremediation in administering contaminated environment was gradually valued, and researches on it were more than ever before. Now, bioremediation uses naturally occurring bacteria and fungi or plants to degrade or detoxify substances hazardous to human health or the environment. Contaminant compounds are transformed by living organisms through reactions that taking place as a part of their metabolic processes. Biodegradation of a compound is often the result of actions of multiple organisms. There are two main sections in bioremediation. Renovating contaminated water by plants which having special physiological and biochemical functions or directly by microorganisms. Secondly, designing rationally and utilizing biological treatments or circulates to block out or decrease the direct discharge of pollution sources to environment [18].

However, 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 rate of clean-up for a exercise of bioremediation. On the other hand, bioremediation techniques are typically more economical than traditional methods such as incineration, and some pollutants can be treated on site, and they are based on natural attenuation, so the public consider it is more acceptable than other technologies.

3. Microogranism Remediation

Biological treatment most commonly involves the breakdown of contamination into nontoxic forms by microbiological processes [19]. Microorganisms exist naturally or those are cultured specially used into microorganism remediation under controlled conditions to transform toxic contaminates to be non-toxic substance [20]. Microorganism remediation not only controls the water polluted by petroleum and other organic pollutions, but can also administer the water environment contaminated by heavy metals, nitrogen and phosphorus et al.

3.1 Ecological Relationships of Microorganisms & Contaminates

3.1.1 Intergrowth

The degradation of many contaminates is the result of co-metabolism of various microorganisms. One microbe usually cannot directly use the energy produced by its own supersession. Microorganisms of intergrowth provide each other substrates environments to growth. Co-metabolism is main mechanism of degradation of lots of contaminates.

3.1.2 Alternation

Alternation is very popular between degradation of microbes. Microbes satisfy needs of nutrition between each other, and benefiting together. The metabolized outcome of one microbe creates an ecological position to another microbe, and promoting the replace of population of communities.

3.1.3 Competition

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There are competitions of nutrition and environmental factors existed in degradation microorganisms and other creatures. When other creatures are more likely to gain nutritional substrates, light and room etc. in environment, the speed of growing and breeding is increasing, and they become the dominant species, the growth of degrading microbes will be limited.

3.1.4 Remediation for heavy metal contamination

The mechanisms of heavy metal-contaminated microorganism remediation are mainly including conversions of immobilization and pattern of heavy metal, which are affected by microbes. The conversion of immobilization is completed by some groups with capacities of coordination in the surface of the cell wall of microorganisms. These groups form covalent or ionic bond with absorbed metal ions to absorb heavy ions, and the capacity of absorbing metal sometimes is better than synthetic chemical adsorbent. For instance, the volume of *Rhizopus nigricans* hyphostroma absorbing plumbum can reach 135.8 mg (unprocessed) or 121 mg (embedding by gelatin) per gram [21]. The change of heavy metal morphology or the decline of biological effectiveness of heavy metal is affected by microbial life activity, which is achieved by morphological transformation of microbes for heavy metal. Eventually, it relieves the pollution of heavy metal. There is a research shows that the cashmere of cyanobacteria and algae can remove heavy metals in wastewater. Sulphate reducing bacterium produces H_2S, which reduces heavy metals to be sulphide with very low water solubility to deposit, such as ZnS, CdS and CuS. In this way, it controls the heavy metal contamination [22]. Frankenberger et al. accelerated in situ bioremediation through cultivation, optimized management and adding supplement based on biological methylation of selenium to make it volatile, then decreasing the toxicity of sediments of selenium in Resterson reservoir in California [23].

3.1.5 Remediation for eutrophication

The generation of algae protoplasm in photosynthesis depends on exists of carbon, nitrogen and phosphorus, which are the critical factors for growth of algae as well as the eutrophication of lake. Phosphorus is often regarded as the limiting factor for eutrophication, because the available content of nitrogen in algae is more than phosphorus'. From the rule of British national environmental department, when the overall concentration of phosphorus in the still water is 0.086mg per liter, it comes to the threshold of eutrophication [24]. The point of technologically eliminating eutrophication in lake is to whittle down the nitrogen, phosphorus in water and organic carbon in bed mud. Mechanical dredging method is the most common, water flushing and bioremediation are also effective. Microbes can be used to remove the nitrogen and phosphorus from water with eutrophication. Pinar et al. separated *Klebsiella oxytoca*, which can exist in 1M nitrate, and eliminate it [25]. Photoautotrophic microorganism *Phormidium bohneri* can also remove nitrogen and phosphorus in certain conditions, and the advantage is the energy coming from solar [26]. The removal of nitrogen by microbes is mainly accomplished with nitrification and denitrification. And the removal of phosphorus by microbes is through the process of absorbing phosphorus of *Aeromonas* et al. on anaerobic or aerobic conditions. Differing from general methods, microbial phosphorus removal technique has a better result, a more stable process, a cheaper cost and an easier operation. Therefore, it is utilized widely, and provides effective means to eliminate the nitrogen and phosphorus in water [27].

3.1.6 Remediation for petroleum spill

Production, application and emission of various petroleum products, oil spill incident make the petroleum pollution become main contaminations in ocean environment. And controlling it has become research focus to environmental experts in the world. Natural microorganisms in most

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Received: 2014/07/19, published: 2014/07/31

environments can degrade and transform petroleum. Bioremediation which is developed based on the biological degradation aims to enhance the speed of oil degradation and eventually converting petroleum pollution to be innocuous outcomes. April TM et al. separated four *Pseudalleschena boydiis* which could degrade petroleum in contaminated soil. Three of them were able to degrade linear aliphatic petroleum hydrocarbon, another could degrade volatile chain alkanes, such as ethane and propane [28]. Toyohart Hozumi et al. found that Nakhodka oil spill accident changed the community structure of microbes in polluted coast area, and those microbes with the capacity of degradation became dominant species. On the natural conditions, only saturated hydrocarbons and some small molecule aromatic hydrocarbons were degraded easily, other degradations of heavy aromatic hydrocarbons, colloidal matters and bitumen et al. were pretty slow. But after adding *Terra Zyme* TM, the rate of degradation of dead oil was raised [29]. Numata et al. fostered a new microbe, which could degrade 30 mg of trichloroethylene per liter in 24 hours and half of 100 mg per liter [30]. Someone had already separated several thermophiles in environments of the United Arab Emirates, they had the maximum increasing speed in temperature of 60 to 80 degree Celsius and break down long chain organic molecules to be CO_2, H_2O et al. in 40 degree Celsius [31]. Some psychrophiles could grow and reproduce in 0 degree Celsius or cooler temperature, even so, oil degradation bacteria enriched at oil spill location showed their good potential capacity of remediation [32].

3.1.7 Remediation for organic contamination

The vigorous growth of modern industry and ocean transportation has greatly improved people's life. On the other hand, the negative effect in the environment it brings becomes more and more apparent. The accumulation in environment and cumulative effect in food chain of toxic pollutants are not an environmental problem to be ignored. Microbes have potentialities of degrading most organic compounds to be inorganic substance, like water, carbon dioxide and minerals, so they are the primary factors in process of degradation. ^{3}H-Thymidine infiltrating and ^{14}C-Glucose method et al. are firstly applied in the west maritime space of Xiamen in China to determine relevant parameters, the results indicated that nine epoxy units of octylbenzene epoxy resin or two epoxy units of nonylbenzene epoxy resin have the best effect for desorbing onions, benzene and phenanthrene [33].

3.1.8 Remediation for pesticide pollution

The ocean environment, especially beaches and coastal waters, to some degree are contaminated by pesticides. People have separated many microbes, including bacteria, fungi, actinomycetes and algae which could degrade pesticides. The research of bacteria is most, next is fungi. Herbicide is utilized commonly in recent years, and following by the environmental pollution. Therefore, the isolation and application of microorganisms for degrading herbicide become active research areas now [34, 35]. Alian et al. added napropamide into soil to bring out the production of the pesticide-degrading bacteria [36]. Ronald et al. put vinclozolin into soil continuously to induce and screen pseudomonas of pesticide-degrading bacteria [37]. It is found that degrading gene of pesticide-degrading bacteria mostly existed in plasmids, and expressed in other bacteria strains through plasmid transfer. Meanwhile, one bacteria strain was able to carry multiple degrading plasmids, thus expanding popularities and enhancing capacities of degradation [38].

3.2 Phytoremediation

Although the application of biotechnology of microbes has been successful with petroleum-based constituents, microbial digestion has met the limited success for widespread residual organic and metals pollutants. In natural ecosystems, plants act as filters and metabolize substances generated by nature. Sometimes, plants are also used to accelerate the rate of degradation or to remove contaminants, either on their own or alongside with microorganisms [39]. Phytoremediation is an emerging technology with plants to remove contaminants from soil and water [40, 41]. Success of any remediation system based on plants depends on the interaction of root exudates and in-situ microorganisms.

3.2.1 Types of Phytoremediation

3.2.1.1 Phytoextraction

Phytoextraction is the process of plants to accumulate contaminants in roots and aboveground shoots or leaves. It removes metal pollutants (Cd, Pb, Zn, As etc.), and accumulates them in parts of plants. *Viola baoshanensis* [42, 43], *Sedum alfredii* [39] and *Rumex crispus* [44] are some examples.

3.2.1.2 Phytodegradation

Phytodegradation is the breakdown of contaminants through the activity existing in the rhizosphere. Due to presences of proteins and enzymes, plants and associated microorganisms degrade organic pollutants, like DDT. We could find this mechanism in *Elodea canadensis* [45] and *Pueraria thunbergiana* [39].

3.2.1.3 Rhizofiltration

Rhizofiltration is a technique of water remediation involving the uptake of contaminants and mainly metals (e.g. Zn, Pb, Cd, As) from water and aqueous waste streams by plant roots. Some studies of *Brassica juncea* [46] and *Helianthus annus* [39] can present it.

3.2.1.4 Phytostabilization

Phytostabilization is a technique using plants to reduce the bioavailability of pollutants (e.g. Cu, Cd, Cr, Ni, Pb, Zn) in the environment, e.g. *Anthyllis vulneraria* [39], *Festuca arvernensis* [47] and *Koeleria vallesiana* [48].

3.2.1.5 Phytovolatilization

Phytovolatilization means to the uptake of organic contaminants from water and using plants to volatilize pollutants (e.g. Se, CCl_4, EDB, TCE). *Stanleya pinnata* [39] and *Zea mays* [49] are working in the similar way.

3.2.3 Remediation for heavy metal contamination

Plants which lived in high content of metal environment gradually shape resistance to metals in the long bio-adaptive evolutionary process. Some plants can largely intake and store metal elements from environments, and grow normally, they are called Metal Hyperaccumulators. This concept was first proposed by Brooks in 1977 and used in hyperaccumulators of nickel, then expanded to all Metals Hyperaccumulators [50]. Phytoremediation of heavy metal contamination means to transfer metal contamination into certain place of plants in the form of ions, then fixing it in certain environmental room by plants to prevent it from further spreading. Szymanowska A. et al. researched contaminated lake and found the concentration of Cr, Cd, Fe, Ni, Zn et al. in *Nymphaea alba*, *Nuphar llltellm*, *Cerat hyllum demersum*, *Phragmites communis*, *Typha latifolia* and *Schoenoplectus lacustris* have preferable correlation with that in environments. They inferred that aquatic plants stored cadmium and chromium mainly from sediments of the lake, and stored iron from water [51]. H. Dahmani-Muller et al. researched the tolerance and absorption mechanism of several plants to heavy metals around a metal smelter. The result indicated that C. *halleri* was the hyperaccumulator of Zn and Cd, and the enrichment site focused on leaves above ground [52]. Entry et al. found that sunflower can enrich radioactive element U excessively, and the content of U is 5,000 to 10,000 times of that in water [53]. For insoluble and not soluble metals, like Pb, Cu, Au, Pt, chelate-induced remediation contributes to plants absorb metals [54].

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Received: 2014/07/19, published: 2014/07/31

Algal bioremediation, using algae to remove pollutants from water, has been well studied over the past 40 years [55-58]. Since the 1980s, considerable research effort has been devoted to the development of algal biosorbents for remediating pollutants, particularly heavy metals [59]. Small scale laboratory experiments have shown it is possible to cultivate freshwater algae in these metal-contaminated waste streams with the addition of limiting macronutrients such as nitrogen and phosphorus [60]. Adey et al. found that algae bed filtration system can also be used to clear heavy metals. However, this applied technology is not proficient and popular now [61].

3.2.4 Remediation for Eutrophication

Aquatic advanced plants usually grow root systems and large leaf area, which can intake nutrients, such as nitrogen, phosphorus in water, then control the eutrophication and get water purified. In addition, there are no chemicals used in treating process, and not producing harmful by-products, therefore it is a nice processing technology to environmental protection. Dai M. et al. discovered that the recovery of *Potarnogeton crispus* L. could effectively reduce the concentration of nutrients and contents of suspended matters of water, thus improving conditions of eutrophication [62].

The earliest use of algae in pollution control was developed for sewage wastewater where its uptake of nitrogen and phosphorus was harnessed [55]. The capacity of luxury uptake of some algae or bioconcentration of nitrogen and phosphorus has also been utilized for bioremediation of waste water in aquaculture (integrated aquaculture) [63].

3.2.5 Remediation for Organic Contamination

The sophisticated physiological and biochemical characteristics of plants can degrade polycyclic aromatic hydrocarbons, polychlorinated biphenyls et al. to be non-toxic components. The root systems of plants can release organic acid, amino acids, sugars, proteins, nucleic acids et al. into rhizospheric soil, and these excretions contain organized enzymes, which can degrade and transform organic compounds, make plants remediate polluted water body become possible [64]. According to the report of Betts et al., the result of remediation of surface water in Army Ammo Depot of Iowa State in USA polluted by exploders by aquatic plants and wetland plants indicated that *Potamogeton*, *Pueraria lobota* and *Ceratophyllum demersum* and poplars cultivated around the wet land can dislodge 0.019 mg/L TNT per day [65]. Roxanne et al. researched phytoremediation of surface water contaminated by TNT, found that removal of degradation can reach one hundred percent [66].

3.2.6 Remediation for Pesticide Pollution

Aquatic plants have large lipid-rich epidermal area, which can surely be utilized to absorb lipophilic organochlorine pesticides. Duckweed, waterweed et al. can totally enrich DDT from water in six days under aseptic conditions, and one percent to thirteen percent of DDT can be degraded to be DDD or DDE [67]. Furthermore, the addition of duckweed, waterweed or hornwort can significantly reduce the concentration of metolachlor in surface water [68].

3.3 Animal Remediation

Aquatic animal communities have certain remediation effects to eutrophication of water. For example, stocking zooplankton and breeding fish can reduce impacts of algae in water. *Anodonta* has dramatic capacity to purify Pb^{2+}, Cu^{2+}, Cr^{2+} et al. naturally, but with longer period of treatments and more cost than general methods. Enhance, animal remediation is chiefly applied as a biological indicator of heavy metal pollution in environments, but less used in pollution management. Niu M F et al. found that earthworms exhibit a phenomenon of significant enrichment for Cd in sediments of rivers [69]. Lasat thought that researches of interaction among animals, microorganisms and plants in the soil are important to the further development of technology of bioremediation [70].

3.4 Other Methods Applied in Bioremediation

3.4.1 Addition of Nutrient Activators or Surfactants

The deficiency of nutrients is the major limited factor for microbes to degrade contamination in water, therefore adding nutrient salts can enhance the metabolic activity of microorganisms. Levy et al. created a neurotransmitter of reduction agent for pollutants to control organic and inorganic contamination in aquatic and terrestrial environments. Besides microbial agents, there are nutritional agents inside, which can remediate water polluted by oil, diesel, gasoline et al. [71]. Stanish I et al. used biostimulation produced by EIT in USA to make the locale remediation test, found it could promote degrading organic matters in water and significantly remove contaminations like ammonia nitrogen and phosphorus [72].

3.4.2 Precipitation & Ion Exchange

Precipitation is defined as non-directed physico-chemical complexation reaction between dissolved contaminants and charged cellular components. Ion exchange is to remove ions from the aqueous phase by exchanges of cations or anions between the contaminants and mediums. Oxidants and pH in ground water may affect the exchange. There was a research showed that humic acids and anthraquinone compounds were as electron acceptors in the process of degradation of organic matters [73].

3.4.3 Reverse Osmosis

Reverse osmosis is a way by an applied pressure forcing the flow of water from a more concentrated solution to a less one. It can be used in desalination of sea water and remove pollutants and microorganisms, but cost high energy.

3.4.4 Microfiltration

Microfiltration membranes are used at a constant pressure to remove dissolved solids rapidly. They are commonly used in wastewater treatment, and the rate of reuse of original waste water is more than 90%.

3.4.5 Electrodialysis

Electrodialysis uses cation and anion membrane pairs with exchange to remove the dissolved solids efficiently, but it is only exploited commercially.

3.5 Factors of Bioremediation

Bioremediation process is a complex system with many factors. These factors include biological, environmental and pollutants' factors.

3.5.1 Biological Factors

The energy source and the carbon source are the main requirements for microbes to adapt and grow at subzero temperature, 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. Once the enrichment of the capable microbial populations and production of toxic metabolites are formed, environmental hazards can be degraded or remediated.

Aerobic microorganisms are in the presence of oxygen, many of them use contaminants as the sole source of carbon and energy. Anaerobic bacteria is in the absence of oxygen and used less frequently than aerobic bacteria. Some fungi have the ability to degrade extremely environmental pollutants. What's more, there is the microbial interaction between different microorganisms.

3.5.2 Environmental Factors

Nutrients are the basic building blocks of life and allow microbes to create the necessary enzymes to break down the contaminants. They need carbon, nitrogen, oxygen, hydrogen to constitute 95% of the

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Received: 2014/07/19, published: 2014/07/31

weight of cells. They also need phosphorous, sulfur and potassium.

Optimal environmental conditions are good for the degradation of contaminants. Temperature, pH, moisture etc. readily affect microbial growth and activity. The range of temperature for microbial activity is 15 to 45 °C, above them, the cell would die. 20% to 30% of water-holding capacity and 6.5 to 8.0 of pH will be beneficial to microorganisms. The soil should not have low clay or silt content, and some heavy metals can promote microbial growing.

3.5.3 Pollutants

Too low concentration of contaminants affects the survival of the microorganisms. Pollutants cannot be too toxic. Some types of contaminants can be degraded only by especial microbes. For degradation, it is necessary that bacteria and contaminants to be in contact. This is not easily achieved, as neither the microbes nor contaminants are uniformly spreading in environments.

3.6 Status

Bioremediation is a natural process and is therefore perceived by the public as an acceptable waste treatment process for contaminated water. Many compounds that are considered to be hazardous legally can be degraded. Residues of the treatment are usually harmless products. Bioremediation can be proved less expensive than other technologies to clean-up contaminants. It also eliminates the potential threats to human health and environment.

On the other hand, bioremediation is limited to those compounds that are biodegradable. Not all compounds are susceptible to rapid and complete degradation. It requires the presence of metabolically capable microbial populations, suitable environmental conditions for growth, and appropriate levels of contaminants as important factors. Furthermore, bioremediation often takes longer time than other treatment options.

4. Discussion

Although bioremediation technology is promising and has been proven to be effective, the relationship between bioremediation and ecological food chain and potential impacts of them to human health and environment are still unknown, further research is needed to develop and engineer bioremediation technologies that are appropriate for sites with complex mixtures of contaminants. There is no accepted definition of “clean”, evaluating performance of bioremediation is still difficult, and there are no acceptable endpoints for bioremediation treatments. If used properly, bioremediation has minimal adverse effects since it can be applied with little or no disruption to contaminated sites. In short, Bioremediation should be improved by us through biotechnology tools to enhance its exploitation for managing environmental pollution in a sustainable pattern.

Acknowledgements

The financial support of Yangtze University Laboratory Research Center is acknowledged.

Conflict of Interest

We declare that we have no conflict of interest.

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Received: 2014/07/19, published: 2014/07/31