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Bioremediation of Hazardous Pollutants Using Fungi

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Abstract - Use of chemicals in industrial processes, agricultural practices, nuclear experiments and various areas of our daily lives result in the release of potential toxic chemicals into the environment either on purpose or by accident. Chemicals that are known to pollute the environment include heavy metals, drugs, hydrocarbons, halogenated solvents, endocrine disrupting agents and agricultural chemicals. After their release, these pollutants are transported through the soil, atmosphere and water sources polluting them, thus posing a serious problem for survival of mankind. In the past, traditional method of disposing hazardous pollutants was by digging a hole and filling it with waste material but this method of waste disposal was difficult to continue due to lack of new places to dump. Many physical and chemical based technologies for waste disposal like high-temperature incineration and chemical decomposition methods have evolved in the years. Though these techniques were very effective at reducing a wide range of contaminants, at the same time they had several drawbacks like being complex in nature, uneconomical, and were not easily accepted by the public. Thus focus was shifted towards using modern day bioremediation process as a suitable alternative. Bioremediation is a microorganism mediated transformation or degradation of contaminants into nonhazardous or less-hazardous substances.

In this process the contaminant or pollutant is used as a nutrient or energy source by the microorganism and the enzymes secreted by the microorganisms attack the pollutants and convert them to less hazardous products. Among the various microorganisms, fungi possess the biochemical and ecological capacity to degrade environmental organic chemicals either by chemical modification or by influencing chemical bioavailability. Ability of fungi to form extended mycelial networks, the low specificity of their enzymes and their ability of using pollutants as a growth substrate make fungi well suited for bioremediation processes. In contrast to bacteria, fungi are able to extend the location of their biomass through hyphal growth in search of growth substrates. A bioremediation process to be effective, manipulation of environmental parameters to allow microbial growth and degradation to proceed at a faster rate are required. By integrating proper utilization of natural or modified fungal capabilities with appropriate engineering designs to provide suitable growth environment, bioremediation using fungi can be successful in treating hazardous pollutants.

Keywords: fungi, Bioremediation, hazardous, pollutant, mycoremediation,

I. INTRODUCTION

The quality of life on earth as decreased rapidly due to development in technology and science which has led to the production of a lot of harmful pollutants. Pollutants of concern include hydrocarbons, heavy metals, drugs, pesticides and explosives. The traditional method of disposal of wastes was by digging a hole and filling it with the waste but this method had its disadvantages due to the lack of new place to dump every time and risks involved. This method was not cost effective and it was difficult to find new landfill sites for the final disposal of the material. The cap and contain method seemed to be the only solution since the contamination remained on site and could be monitored and maintained. So a better approach was to completely destroy the pollutants to transform them to less polluting substances. Many physical and chemical methods of treating the have been used but they have several drawbacks like being uneconomical, complex and lacked public acceptance especially in the case of incineration the exposure to the contaminants may increase for both the workers at the site and nearby residents over period of time.Thus eco-friendly, cost effective treatments are the need of the hour. In bioremediation degradation of toxic pollutants was carried out either through intracellular accumulation or via enzymatic transformation to less or non-toxic compounds (Brar *et al.,* 2006).

II. HAZARDOUS POLLUTANTS

Hazardous pollutants are defined as any waste that would be a present or future threat to humans or the environment. They can also be defined as unwanted materials that exhibit hazardous characteristics. Due to increase in the number of industries a lot of wastes have been let out into the environment. These pollutants are toxic and persistent in nature for a long time. They remain in the soil and water even after their use has been discontinued they can enter the food chain. These pollutants also have the ability to bioaccumulate within the tissue of animals. Thus biomagnifications occurs over the period because of the increasing levels of toxic compounds within the body. Some properties of hazardous pollutants are its flammability, explosive nature, corrosiveness, toxicity and bioaccumulation. The short term and long term hazards of hazardous pollutants are as shown in Table 1. Sometimes eutrophication takes place due to the presence of inorganic pollutants and acute and chronic diseases occurs due exposure to these pollutants.

Table 1: Short term and long term hazards of hazardous pollutants

Short term hazard	Long term hazard
Damage due to direct contact	Biomagnifications
Inhalation of the fumes from the toxic pollutants	Movement of the pollutant to other parts of the environment
Risk of fire/explosion	Formation of a more toxic secondary product

III. PRINCIPLES OF BIOREMEDIATION

Compared to conventional clean up technologies bioremediation is a low cost and eco-friendly technology. Bioremediation does not involve only the degradation of pollutants but also, at times it is sufficient to remove the pollutant from the environment without degrading it (Broda, 1992). Bioremediation is a technology that uses biological activity to reduce the concentration or toxicity of the hazardous pollutant (Mueller 1996). Different microorganisms transform or degrade chemicals in the environment. Various organisms like bacteria, fungi, algae, and plants have been used for bioremediation of pollutants and cleaning up our environment (Leung, 2004) as shown in Figure 1.

The contaminant compounds are transformed by living organisms through reactions that take place as a part of their metabolic processes; the microorganisms enzymatically attack the pollutants and convert them to less harmless products. The manipulation of environmental parameters is needed to promote microbial growth and activity. For bioremediation to take place effectively various factors are required like existence of a microbial population which has the ability to degrade the pollutant, availability of the contaminant to the microbial population and various environmental factors like type of soil, temperature, pH, electron acceptors and nutrients (Vidali, 2001, Dua *et al.*, 2002). Usually microorganisms indigenous to the environment are used but if microbes are not present then they can be added from another source to promote bioremediation and this process is called bio augmentation.

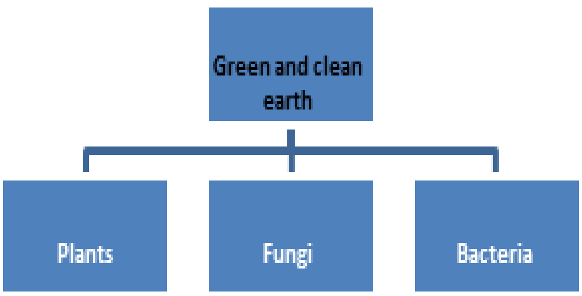

Fig 1: Process of waste bioremediation

The microorganisms can be isolated from any environment and they can adapt and grow at any extreme conditions. The main requirement for a microorganism to survive is an energy source and a food source. Since microbes can adapt to any condition they can be used to degrade or remediate environmental hazards (Ruldolph *et al.*, 1996). Bioremediation like any technology also has its limitations like some contaminants are resistant to microbial attack and they are degraded either slowly or not degraded at all.

IV. FACTORS REQUIRED FOR BIOREMEDIATION

4.1. Nutrient and environmental factors

For a bioremediation process to take place three essential components are required. They are microorganism, food and nutrients. These three components are known as bioremediation triangle as shown in Figure 2. Except active volcanoes microorganisms are found almost everywhere on earth, so for a successful bioremediation process to take place food and nutrients are the missing ingredients. Microorganisms usually obtain food from the soil or water where they live thus if a contaminant is available it becomes an additional food source for the microorganisms (Tang *et al.*, 2007). The contaminant serves two useful purposes for the microorganism firstly as a source of carbon needed for growth and secondly for proving energy. The microbe breaks the chemical bonds and transfers the electrons away from the contaminant thus obtaining energy (Rockne and Reddy, 2003). This is known as an oxidation-reduction reaction. The contaminant which loses its electrons is oxidized and the chemical that gains the electrons (electron acceptor) is reduced. Thus the energy gained from the electron transfer is used along with the carbon and electrons and help in the production of more cells. When oxygen is used as the electron acceptor it is called aerobic respiration and the end products are carbon dioxide and water with an increase in the microbial population. In anaerobic respiration nitrate, sulfate, iron, or carbon dioxide are used as the electron acceptor instead of oxygen. When oxygen has been depleted by aerobic respiration or when there is no sufficient oxygen then anaerobic respiration takes place (Colberg and Young, 1995).

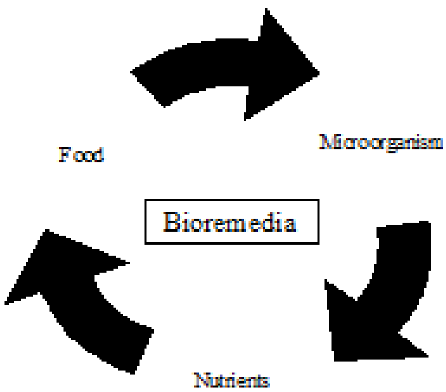

Fig 2: Factors required for bioremediation

Bioremediation process can take place only when other nutrients like nitrogen, phosphorus, trace elements and moisture are also available to the microorganism. Moisture is also a important factor needed for the organism to survive and grow since it is the only way by which they can transport food. Besides moisture, nitrogen (ammonia) and phosphorus (orthophosphate) are two major nutrients needed for the microorganisms. The microorganisms also require minor elements such as sulfur, potassium, magnesium, calcium, manganese, iron, cobalt, copper, nickel, and zinc.

Microbial growth and activity are affected by pH, temperature and moisture even though they have been isolated from extreme condition. So if the soil is acidic then the pH can be raised by adding lime. Temperature also affects bio-chemical reactions rates, and their rates double for each 10ºC rise in temperature and after a certain temperature they die. Thus to prevent this plastic coverings are used to enhance solar warming.

V. TYPES OF BIOREMEDIATION TECHNIQUES

There are two basic types of bioremediation techniques

5.1. In-situ bioremediation

In situ bioremediation is when microbial activity is stimulated by the addition of microorganisms and nutrients and the optimization of environmental factors at the contaminated site itself. Oxygen and nutrients are supplied to the contaminated soils to stimulate naturally occurring bacteria to degrade organic contaminants. This method can be used for the remediation of both polluted soil and groundwater. Since it is cheaper and uses harmless microbial organisms to degrade the chemicals this method is preferred.

5.2. Ex-situ bioremediation

Ex-situ bioremediation is when the contaminated material are transported from the contaminated site to a specifically designated area and treated by landfarming and composting methods. This technique has more disadvantages than advantages since it involves the excavation or removal of contaminated soil from ground which is costly.

VI. MYCOREMEDIATION

Mycoremediation is a form of bioremediation in which fungi are used to decontaminate the area. Fungi are found in soil, in fresh and sea water, inside the bodies of plants and animals, and traveling through the air as spores. While they often are found functioning together with bacteria and an array of microorganisms, it is fungi that can especially handle breaking down some of the largest molecules present in nature (Fernandez-Luqueno *et al.*, 2010). The main function of fungi in the ecosystem is decomposition, which is performed by the fungal mycelium. The fungus secretes a number of extra cellular enzymes and acids that break down lignin and cellulose, which are organic compounds composed of long chain of carbon and hydrogen present in the plant fibre which is similar in structure to many organic pollutants thus fungi can be used to degrade these pollutants. Both fungi and bacteria are used for degrading environmental pollutants but fungi are particularly more suitable because some pollutants cannot be degraded by bacteria. Bacteria contain little energy, have a low bioavailability and cannot degrade substances having rare structural elements. Filamentous fungi are more advantageous where translocation of essential factors (nutrients, water, the pollutant itself) is required for the degradation of environmental chemicals by translocating resources between different parts of their mycelium. Fungi also release extracellular enzymes which allow for digestion of energy sources in their surroundings and further diffusion of these molecules through the substrate towards the fungus (Mai *et al.*, 2004). Fungi are also known to produce large quantities of exudates that serve as auxiliary carbon sources for pollutant-degrading bacteria. Fungi degrade PAH more than bacteria. Fungi can degrade high molecular-weight PAHs, whereas bacteria are best at degrading smaller molecules (Peng *et al.*, 2008). Fungi are especially well-suited for PAH degradation compared to bacteria, they can degrade high molecular-weight PAHs, whereas bacteria can degrade only smaller molecules. Thus bioremediation is an acceptable way of treating hazardous pollutants and is very advantageous due to its eco-friendly and cost effective nature. But bioremediation like any technology as some disadvantages as shown in Table 2.

Table 2: Advantages and disadvantages of bioremediation

Advantages of bioremediation	Disadvantages of bioremediation
Bioremediation is a natural and acceptable process for treating the contaminant.	Limited to compounds that can be degraded
The end products of the process are harmless products	Sometimes the end product of biodegradation are more toxic and persistent than the parent compound
Complete destruction of pollutant takes place	All factors like environmental condition and nutrient amount should be perfect for bioremediation to take place
Often carried out on the site, eliminating the need to transport the pollutant and the potential threats due that	Highly specific
It is a cost effective and eco-friendly technology	Bench and pilot scale studies cannot be extrapolated to full scale field operations
	This technology takes longer time than other methods
	No acceptable endpoints for bioremediation treatments.

VII. CONCLUSION

The main aim of this paper is to show how fungal bioremediation, a natural process can be used in the treatme nt of contaminated environments. Fungi have an astonishing potential to clean up environments. Research shows that there might a fungus to degrade every type of persistent hazardous pollutant. Bioremediation is an eco-friendly way of treating hazardous pollutants and is gaining attention nowadays. Different types and approaches of using microorganisms have been developed and used in bioremediation. So by understanding microbial communities and their response to different natural environment, new techniques of bioremediation will offer a potential for significant advances. Bioremediation also offers an efficient and cost effective way to treat contaminated ground water and soil. Though it as some disadvantages, it is outweighed by all its advantages, which is why its popularity has increased in the recent years for the rejuvenation of polluted sites. The application of bioremediation must therefore be applied wisely with a word of caution. Thus a new species of fungi capable of surviving in any polluted environment can face the challenge of degrading

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any persistent pollutant produced by a technology dominated world.

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