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A Comprehensive Literature Review on Bioremediation of Heavy Metal Waste Using Microorganisms

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Abstract

Managing the urban solid waste is a subject of great apprehension globally. In contemporary times, lots of research studies relating to the usage of competent procedures to minimize the volume of the waste have been growing. In this perspective, the usage of bioremediation procedures for the elimination of toxic metals from waste is attaining substantial consideration. Bioremediation is the procedure which by means of microorganisms eliminate the waste. An extensive variety of microorganisms containing fungi, bacteria, yeasts and algae can be active methylators, so as to convert the toxic varieties. Though microorganisms would not be able to terminate the metals, they can modify chemical properties through some mechanisms. This study would deliver an apprise regarding the approaches obtainable for the remediation of metal-riched waste by means of microorganisms with evaluation of their benefits and flaws where emphasis is on the hazardous metals. Different types of microorganisms used in bioremediation procedures are deliberated in detail as they have ability to biosorb hazardous metal ions. This study reviews current information on several features of the applications of bioremediation along with the difficulties to its commercial accomplishment.

Introduction

Hasty development and anthropogenic actions like failed practice of fossil fuel burning, agro-chemicals and discarding of sewage sludge have instigated soils and water to be sternly polluted with heavy metals (Sivasangari et al. 2016). Ecosystems also got irretrievable damaged by the heavy metals from the mining and casting of ores, automobile exhausts, waste from storage batteries, use of fertilizers, pesticides etc. Heavy metals are non-biodegradable and persist in the environment. Hence, remediation is required to avoid heavy metal leaching or mobilization into environmental segments and to facilitate their extraction. The metals that pollute the waste are usually found in the surroundings comprising lead, nickel, chromium, zinc, mercury, arsenic, uranium, selenium, cadmium etc. Apart from high toxicity, hazardous, these metals have an adversative effect on the human, fauna and flora and they are non-biodegradable.

Numerous procedures such as electrochemical treatment, ion exchange, precipitation, osmosis, evaporation, and sorption are usually employed to eliminate heavy metals from the waste (Fomina and Gadd 2014; Kadirvelu et al. 2002). But, those procedures are neither cost-effective nor environmental friendly. On the contrary, bioremediation procedures are capable to remove the heavy metals, when the conventional methods fail to work. Moreover, bioremediation procedures are eco-friendly and economically practicable choice. The procedure is centered on the binding ability of the biological organisms where microorganisms can be deliberated as a biological instrument for metal elimination (Riggle and Kumamoto 2000). There are numerous researches regarding the removal of the heavy metals using microorganisms for the removal of heavy metals from the waste as substitute to conventional methods (Texier et al. 1999). Bioremediation by microorganisms is effective because of the act of microorganisms on heavy metals when present in thinned solutions. Detailed information on the bioremediation procedure employing several microorganisms, mechanisms, efficacy, and existing uses are delivered with propositions to overhaul the constraints.

Waste comprising of heavy metal

Elements of higher atomic weight than *Fe* are considered as heavy metals. Though, *Cr*, *As* and *Se* are usually mentioned as heavy metals (Pierzynski et al. 2000). Heavy metals can be toxic to humans reliant on the contact intensities like *Hg, Pb, Cd, Cu, Ni*, and *Co*. Heavy metals are prominent toxins, non-biodegradable and simply gathered in living beings (Zhuang and Gao 2013). The harmfulness of the heavy metals is reliant on the respective forms while researches on bioremediation usually deliberate the total amount present. Heavy metals polluted in soil and waste can bring together and persevere for long and is injurious to dynamic procedures involved in microbial cycles (Grath et al. 1994). The toxicity of heavy metals is reliant on their form and binding properties. Variations in the ecological situations can change heavy metals from the solid phase to the liquid phase letting the possible toxicities to the liquid waste too.

There are numerous researches regarding the removal of the heavy metals existing in the environment including reverse osmosis, adsorption, redox procedure which are deliberated to be wasteful due to cost ineffective. In bioremediation usually employing microorganisms, toxic chemicals are transformed into less toxic by biological processes (Nicolaou et al. 2010). The technology uses the metabolic potential of microorganisms to remove the heavy metals from the waste and it is a sound substitute with low cost and high efficacy (Watanabe 2001). Microorganisms can convert harmful heavy metals into nontoxic or less toxic metabolites. Microorganisms such as fungi, bacteria, yeast, algae are used in case of bioremediations which can endure polluted environments as they can exploit the pollutants as possible source of energy.

Categories of microorganisms used in bioremediation

Bioremediation is centered on the activity of one or more microorganisms (Nicolaou et al. 2010). There are numerous studies where several microorganisms have ability to biosorb harmful ions of heavy metal (Singh et al. 2014). Cases of microorganisms used in bioremediation procedures for heavy metals are *Pseudomonas veronii, Kocuriaflava, Bacillus cereus*, *Sporosarcinaginsengisoli* which are bacteria (Vullo et al. 2008; Achal et al. 2011; Kanmani et al. 2012; Achal et al. 2012); *Penicilliumcanescens, Aspergillus versicolor, Aspergillus fumigates* which are fungi (Say et al. 2003; Tastan et al. 2010; Ramasamy et al. 2011); *Cladophorafascicularis, Spirogyra spp., Spirullina spp.* which are algae (Deng et al. 2007; Mane and Bhosle 2012) and *Saccharomyces cerevisiae* and *Candida utilis*which are yeast (Machado et al. 2010; Kujan et al. 2006). For functioning bioremediation, microorganisms should react with the contaminant senzymatically and alter them to innocuous substances (Sharma 2012). Microorganisms have advanced tools allied with resistance to harmful heavy metals and converting them harmless (Mejare and Bülow 2001). Some microbes are associated with the procedure of enzymatic degradation. Though majority of the bioremediation methods are active in aerobic settings, degradation of microorganisms occurs in anaerobic settings (Sharma 2012). Different categories of microorganism are essential for operational remediation as various types of contaminants can be present in the waste. Though, there are many options, microorganisms reliant on the chemical nature of the contaminants and chosen cautiously as they endure limited amount of pollutants. The efficacy of the degradation procedure is associated with the potential of the specific microorganism. The use of biotechnology to the removal of heavy metals from the waste is a comparatively novel topic. An improved comprehension of the procedures by which microorganisms apprehend heavy metals has been collected with an eye to maximize the efficacy for environmental complications related to the presence of heavy metal in wastes with new methods like bioleaching, biosorption, bioremediation etc. (Rahman et al. 2014). In this context, the central methodology is the genetic engineering where through some reactions modified microorganisms can alter from the inorganic form into the organic form. In addition to the upsurge of the solubility by the microorganisms, modified microorganisms can enhance their resistance by aspects linking the solubility of heavy metals. On the other hand, their interaction with other aspects such as sorption, precipitation, changes in *pH* can reduce the heavy metals in activeness in the surroundings (Nicolaou et al. 2010). Genetic engineering can be applied to modify the microorganisms and attain fascinating features like *pH* modifications, fast-tracked growth, and acceptance to risky environmental settings. Current studies have confirmed the capability of fungi and yeasts to remove heavy metals from a particular surrounding. With the current developments in genetic engineering, it is comparatively easy to create genetically engineered microorganisms (GEMs) by reorganizing the genes, promoters, etc. and tested for competent bioremediation under laboratory settings (Paul et al. 2005). Current studies demonstrate that certain GEMs have improved capacity to metabolize precise chemicals like hydrocarbons and pesticides (Perpetuo et al. 2011; Singh et al. 2014). Genetic engineering methods on the metabolic potential of microorganisms have permitted the plan of genetically modified microorganisms adept of degrading particular pollutants which creates an opening to generate an artificial blend of genes that are not exist in environment. Some bacteria, such as *Geobactermetallireducens,* can remove uranium in mining operations and from polluted waste (Kumar et al. 2011).

Bioremediation Mechanisms

Microorganisms generally used for the bioremediation of heavy metals are bacteria, algae, fungi, and yeast. Bioremediation can be categorized as bioaccumulation and biosorption. Biosorption is an inert adsorption tool (Ahalya et al. 2003). Many features can affect the biosorption of metals like ionic strength, biomass concentration, *pH*, temperature, particle size etc. (Volesky 2004). The biosorption procedure is inexpensive because the biomass can be found from industrial waste and can be reproduced and reused in several cycles. The selectivity in biosorption is normally low where the metal binding happens by physicochemical interface. On the contrary, living biomass is required for bioaccumulation which is expensive because the procedure happens in the incidence of living cells where reuse is restricted. Yet, procedures involving bioaccumulation usually do better.

Majority of the heavy metals cannot be biodegraded where they incline to accrue in the microorganism (Huang et al. 2014). Many features impact metal accretion like the degree of contact, salinity, metal concentration, temperature etc. It is hard to find thorough information on how the accretion happens in the bioremediation (Varma et al. 2011). The procedure of accretion is intricate and conferring the pathway of metabolism controlled by the metal concentration (Fukunaga and Anderson 2011).

Considerations regarding capability of microorganisms

The competence of a bioremediation procedure depends on the pathway through which the metal fixes to a particular spot of the biomass. In the wake of the absorption of heavy metals, a process of metal secretion or detoxify commences to evade potential harmful effects. Though, microorganisms will not undergo the harmful effects of the incidence of heavy metals while they are kept in detoxified forms (Fukunaga and Anderson 2011). Table 1 depicts capability of different microorganisms such as algae, bacteria, fungi, and yeasts to eliminate heavy metals from the waste (Romera et al. 2007; Murphy et al. 2008; Mata et al. 2008; Nagy et al. 2014; Fulekar et al. 2012; Anahid et al. 2011). Good number of microorganisms has been deliberated for the advancement of effective technology for the elimination of heavy metal ions from contaminants.

Table 1. Example of microorganisms used to eliminate heavy metals

Microorganism	Category	Removed Metal
Algae	*Ascophyllumnodosum*	Pb, Ni, Cu, Cd, Zn
	Cladophorafascicularis	Pb
	Fucusvesiculosus	Cr, Pb, Cd
	Spirogyra spp. and Spirullina spp.	Cr, Cu, Fe, Mn, Zn
	Chlorella pyrendoidosa	U
Bacteria	*Bacillus cereus*	Cr
	Kocuriaflava	Cu
	Pseudomonas veronii	Cd, Zn, Cu
	Sporosarcinaginsengisoli	As
Fungi	*Agaricusbisporus*	Cd, Zn
	Penicilliumsimplicissimum	Ni, Co, Mo, Mn, Fe, Zn
	Aspergillus fumigatus	Pb
	Aspergillus versicolor	Cr, Ni, Cu
Yeast	*Saccharomyces cerevisiae*	Cr, Ni, Cu, Zn
	Candida tropicalis	Cd, Cr, Cu, Ni, Zn
	Pichia guilliermondii	Cu
	Candida utilis	Cd

Recommendations

The unfettered release of waste containing heavy metals in pastoral grounds or water bodies upsurges their likelihoods of inward bound of the food chain over agri-products, fishes and following bioaccumulation. Numerous approaches of bioremediation appropriate to diverse ecological settings have been examined and suggested (Adams et al. 2015; Kumar et al. 2011; Abatenh et al. 2017; Coulon et al. 2010). The strategy, progress, and use of these methods need cautious variety of microorganism. Wide range of investigation has been conducted using precise strains of microbes for bioremediation. Microbes conducted redox responses so as to influence the bioremediation procedures by metal mobilization or immobilization. The procedure of bioremediation of heavy metals is more effective using diverse microbial strains synchronously as a substitute to a single species (Wang and Chen 2009). Progresses in genetic engineering with optimization procedures recommend these tools (Brown et al. 2010). Genetically modified microbes have improved bioremediation possibility for several wastes. The bioremediation method needs an all-inclusive and comprehensive process for methodical, viable and maintainable approaches which can be effortlessly tailored for each of the situations. Furthermore, there is a crucial requirement for management at all stages, together with research establishments, the community, governmental organizations as well as the industries (Sodango el at. 2018).

Conclusions

Activities produce huge amounts of waste comprising toxic heavy metals. Several studies have been carried out in last few decades intended to pull down heavy metal quantities. Significant energy has been put together to advance effective and low cost technologies and relate them to waste management. The possibility for microorganisms to eliminate heavy metals by active and inactive appliances has been revealed to be a remarkable method to contaminated wastes. The competence of such procedures is reliant on the investigational situations, the target contaminant and several other issues. The solicitation of bioremediation procedure in big scale is still a challenge. Additional inquiries intended to the documentation of the appliances involved in the description of biosorbents and progresses in genetic engineering are essential. The optimal capable biomass must be identified considering its cost and availability. Similarly, the microorganisms should be easy to find and can be nurtured. Though some advancement has been achieved in the acknowledgement of the prominence of micro organisms for the detoxification of contaminated wastes, few vital topics still essential are to be addressed. Nevertheless, a fresh task has arisen where additional studies require to be centered on the growth of innovative and clean technologies with marketable viability.

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