EurAsian Journal of BioSciences
Eurasia J Biosci 13, 739-744 (2019)

Bioremidation of heavy metals and role of bacteria

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Abstract

Background and Objective: Contamination of aquatic and soil ecosystems by heavy metals has been always a threat for environment and health of human communities. Bioremidation is a new method that can remove this problem. This study aimed to examine removal of heavy metal by bacteria.

Method: This review study was conducted on studied about bioremidation of heavy metals with bacteria. The applied sites included *Sid.ir-Science direct-ncbi-.ncbi.civilica.* Inclusion criterion was having relevant information and keywords.

Findings: The methods used in bioremidation of heavy metals are more efficient related to physic-chemical methods. Bacteria can reduce concentration and toxicity of heavy metals in different ways due to their various resistance mechanisms compared with heavy metals.

Conclusion: The results obtained from this study showed that bioremidation is an efficient and proper method to remove heavy metals pollution and bacteria can be used for bioremidation of heavy metals from the environment.

Keywords: heavy metals, bioremidation, bacteria, biosorption

Fazaeli D (2019) Bioremidation of Heavy metals and role of bacteria. Eurasia J Biosci 13: 739-744.

INTRODUCTION

Nowadays, expansion of industrialization and extraction of natural resources have led to accumulation of heavy metals in water and soil. Therefore, polluted soils, groundwater, sediments, surface water and air with dangerous heavy metals and toxic chemical materials are the serious threats in the world (Tanzadeh et al. 2016).

The risks of contamination with heavy metals and Biotechnology has been used to ionizing beams of radioactive elements have led to use biotechnology to cope with this issue. In this case, ability of fungi, yeasts, algae and bacteria has been studied by researchers in recent years and obtained results show that biological methods are suitable for removing these elements (Sultani Nezad et al. n.d.).

Many of microbial exopolymers perform as poly-anion under the normal circumstances; it means that they have abundant anionic groups with high affinity for combination with metal cations so that they are used to absorb and remove environmental pollutants in particular heavy and toxic metals (Sultani Nezad et al. n.d.).

Bioremidation is an innovative and hopeful technology to remove and recover heavy metals in polluted land and waters (Tanzadeh et al. 2016).

Metals are essential elements for biological performance of plants and animals, while make disorders in organisms with metabolic functions at high levels. Toxic heavy metals of Se, As, Ni, Ag, Ur, Zn, HG, Pb, Cr, Cd are harmful for plants reducing plant growth, photosynthetic and enzyme activities and leading to harmful effects on quality of soil, production of agricultural products and public health (Kobata–Pendias 2010, Nematian and Kazemeini 2013, Ojuederie and Babalola 2017).

Heavy metals are elements with atomic mass above 40g. Human activities such as extracting, melting, and plating leads to entrance and accumulation of metals in environment (Canli and Alti 2003). The most important ways in which, heavy metals enters to the urban wastewater include insecticides, fertilization, irrigation with wastewater, painting industries, cement factories, rubber manufacturing, car fuel, and metal melting industries (Naysi et al. 2014). Contrary to organic pollutants that can be decomposed to non-toxic elements, metals have stable nature (Canli and Alti 2003).

Presence of heavy metals cause environmental problems for residents of ecosystem violating the standards defined for the environment. There are different effects of heavy metals on human and the most important of them is neurological disorder (Kamari and Farshad Far 2012). As the main disadvantage of heavy metals, they are not metabolized in human body; in fact, heavy metals are not disposed but accumulated in body tissues leading to numerous diseases and problems in body. Moreover, essential minerals and salts in body are

Received: April 2019
Accepted: June 2019
Printed: July 2019

replaced with heavy metals. The most dangerous effects of heavy metals are neurological disorders, cancers, nutritional shortage, imbalance of hormones, obesity, abortion, respiratory and cardiovascular disorders, damage to the liver, kidneys, and the brain, allergy and asthma, endocrine disorders, weak immune system, premature aging, skin disorders, memory loss, joints inflammation, osteoporosis, insomnia and mortality. On the other hand, toxicity and bioaccumulation of heavy metals in plants and animals as well as their presence in food chain lead to numerous risks and ecological effects (Han et al. 2006, Pal et al. 2006).

METHOD

This study was conducted to review studies on bioremidation of heavy metals. After checking topics and abstracts of relevant papers that were published in some databases such as Pubmed Sid ncbi Sciencdirect, the considered papers were selected then studied. In this research, some keywords such as heavy metals, bioremidation, bacteria, biosorption, etc. were used.

FINDINGS

Various physico-chemical strategies have been developed to remove heavy metals from aquatic environments; some of them are filtration and adsorption, chemical precipitation, electrochemical treatment, oxidation-reduction, ion exchange, membrane technology, reverse osmosis, solvent extraction, and evaporation recycling. However, many of these methods have some disadvantages such as lack of technical equipment and monitoring systems, high-energy consumption, lack of economic justification, and low efficiency; furthermore, use of strong solutions for removal of heavy metals leads to secondary pollution in environment (Islami and Nemati 2010).

Accordingly, biological methods have been using for heavy metals treatment in recent years. Some of important advantages of biological method for pollutants removal from the environment are use of these methods in place of polluted areas, lack of danger for environment, high efficiency, and low cost (Meybodi and Khorasani 2014).

Bioremidation is an innovative and hopeful technology to remove and recover heavy metals in polluted land and waters (Tanzadeh et al. 2016).

Different strategies for bioremidation of microorganisms are as follows:

Bioaccumulation in which, microorganisms adsorb heavy metals in an active manner. Bioaccumulation occurs when disposal rate of a material is lower than its absorption rate. Bioleaching that is defined as conversion of solid metals to solution to be used by microorganism. Biosorption that is a physicochemical process in which, pollutant is bounded to the cellular structure in an inactive manner. Biotransformation in which, chemical condition changes inside of the cell. Biomineralization in which, a mineral or organic material converts to another mineral (Dixit et al. 2015, Kelly et al. 2006). Enzyme-catalyzed transformation that is use of enzymes of microorganisms to transform and treat metalic pollutants; this process can be divided to following phenomena:

Metal Precipitation: a number of microorganisms can precipitate heavy metals in the polluted solution to facilitate removal of pollutants.

Redax Transformation: transformation of pollutant metals through oxidation and reduction (redax). Use of metals with high chemical capacity as electron receiver can change oxidation number of pollutant metals and facilitate removal of these metals (Robinson 2000).

Bioflocculation is one another method of bioremidation. Flocculators are metabolites of some microorganisms that can be obtained under a certain cultivation. Non-toxic flocculators decomposable and can treat wastewater. Researchers isolate microorganisms that produce microbial flocculators from different sources such as soil, active sludge, and rivers; sediments. Bacteria, molds and actinomycetes can be named as species that produce microbial flocculators. Polysaccharides are one of essential compounds in MBFs (Microbial BioFlocculent) and flocculation process is based on the generation of connective bridges between compounds (Luo 2007, Shuang Jiang 2009).

Bioaccumulation process uses living cells and depends on the energy generated from microorganisms' metabolism, while absorption mechanism is done by dead biomass without any need to energy of microorganism (Chojnacka 2010). In bioaccumulation process, pollutants are transferred into the cell and bound to the thiol groups-containing proteins called mettalothionein, which are created in response to the toxic metals (Martin–Gonzalez et al. 2006). Changes in morphology and physiology of cell have been along with increase in pollutant concentration within accumulation process (Dessiloniz et al. 2002).

Pros pf biosorption by dead microbial mass: lack of pollution; no time loss for proliferation in medium; no need for inactive biomass for food maintenance; it is difficult to remove biomass from wastewater polluted with heavy metals, while such problem does not occur in dead biomass; dead biomass has lower sensitivity to high concentration of metal ions; there is more diverse biosorption in dead biomass under the environmental conditions (temperature and PH) compared with living biomass (Cabuk et al. 2005, Kapoor and Viraraghava 1999).

Various environmental factors can affect the frequency and availability of metals changing their effective concentration in different places. For survival, microorganisms should control their environment constantly and control the effect of metals in their cytoplasm. Therefore, they can receive enough amounts of essential metals and prevent from accumulation of toxic amounts. This reaction includes absorption systems with high correlation, occurrence of genes that exclude extra metals and proteins that absorb metals (Kafilzade et al. 2013).

Bacteria are the most abundant microorganisms on the earth. There are some mechanisms in microbes that tolerate heavy metals in two ways: by excluding heavy metal from the cell and using them as final electron receptors during anaerobic respiration. Most of the studied mechanisms include metal ion flows out of cell and the genes relevant to tolerance mechanisms have been found on both chromosomes and plasmids. Some bacteria such as *Bacillus* and *Pseudomonas* use such mechanisms (Kafilzade et al. 2013).

Resistant genes against heavy metals and antibiotics can exist on a plasmid (Zeng et al. 2009).

In most of the cases, plasmids create resistance against heavy metals so they can be used to create microbial strains with high antitoxic activity against heavy metals (Aleem et al. 2003). Some mechanisms such as metal adsorption on the cell surface, transformation of toxic metal to a metal with low toxicity, reduction in membrane permeability, and generation of extracellular polysaccharide are the main reasons for bacteria resistance against heavy metals (Zafar et al. 2007).

Bacteria generate an iron-chelating agent called siderophore (Ojuederie and Babalola 2017). Siderophores are extracellular compounds with low molecular weight, iron chelating, and make mineral and organic compounds of iron soluble under iron constraint conditions. In addition to iron, siderophores can create complex with other metals such as Aluminum, Cadmium, Copper, Gallium, Indium, Pb, Zinc and radionuclides. The complex of siderophores with metals increases concentration of metals solution and reduces toxicity of metals in cells. Biosurfactants are extracellular compounds (like siderophores) that can create complex with some metals such as Zinc, Copper, and Cadmium to increase solubility and reduce toxicity of these metals (Rajkumar et al. 2010).

There are different methods to adsorb heavy metals in cells. These mechanisms may be different based on the type of metal and its compounds. Metals can enter into the cells through natural transport processes or in competition to create bind with carrier proteins using molecular or ionic imitation of other compounds such as calcium channels (Islami and Nemati 2010).

Sulfur-reducing bacteria such as *Desulfovibrio desulfuricans* can convert sulfur to hydrogen sulfide also can convert some metals such as Cd and Zn to insoluble form of metallic sulfide (Ojuederie and Babalola 2017).

Membranes of microbial cells are usually composed of polysaccharides, lipids and protein with many of functional groups that can bind to ions of heavy metals; these groups include carboxylates, hydroxylamine, and phosphates (Deanross et al. 2002, Gadd et al. 2003).

Living and dead microbial cells have high efficiency in bioremidation of heavy metals from the environment. Most of the microorganisms have high ratio of surface to volume; hence, they have extensive contact surface for interaction with metal (Huang et al. 2005).

Gram-positive bacteria are more efficient in absorption of heavy metals due to thick cellular wall of multilayer peptidoglycan and teichoic acid. Bacterial cells have some receptors on the surface that react with a certain number of metals based on the type of bacteria, compounds and thickness of cellular wall so that full capacity of binding point leads to full capacity or bacteria in reduction of heavy metal and bacteria is not able to absorb more amount of metal (Sivaprakash et al. 2009).

Lipopolysaccaride layer of Gram-negative bacteria is responsible for efficient adoption of metals. Moreover, it is proved that bacteria release a wide range of specific and non-specific metal adsorbent when responding to high toxicity of metals. Extracellular structures such as capsule and slime layer are also some parts of metal adsorbent. Binding sites in microorganisms usually include phosphate hydroxyl and sulfide groups. Pseudomonas genus is one of bacterial cells that can create extracellular coating polysaccharides and adsorb metals through them (Meybodi and Khorasani 2014).

Numerous studies have been conducted on removal of heavy metals by bacteria; some of them are mentioned herein:

According to Saranya et al. (2017) efficient bioremidation of mercury at a concentration of 250 µg/ml was seen by removal of 60% Hg ion by *Vibrrio fluvialis* bacteria. Therefore, *Vibrrio fluvialis* can be used for eco-friendly removal of Hg.

According to Karimpour et al. (2018) the highest adsorption of Cadmium and lead by dead cells of *aerogenosa Pseudomonas* was reported at 125mg concentration, Ph=7 and 85°C temperature within 90 minutes. These results showed high ability of *P.aeroginosa* bacteria in adsorption of Cd and Pb from aquatic solutions.

Raja et al. (2006) reported that *Pseudomonas Bc15* could adsorb 93% nickel, 65% Pb, 50% Cd and 30% chromium from the culture medium containing 100mg of these heavy metals per liter during 48 hours.

Yadar reported 91% Pb adsorption in the environment containing 10mg Pb by using *Bacillus subtilis*. Pb adsorption by *Bacillus subtilis* is extensively affected by PH, contact time and Pb concentration (Yadav et al. 2012).

Paramesvari et al. (2009) conducted studies on Nickel and Zinc adsorption using living cells of *Bacillus sp, Azatobacter chroococcum, Pseudomonas fluorescence* and showed Ni adsorption percent of 90.098, 86.16, and 84.33 by them, respectively. According to these studies, metal adsorption by these bacteria is affected by metal concentration so that increase in metal concentration leads to reduction in microbial biomass generation and metal adsorption rate.

Pseudomonas can be effective in reduction of soluble chromium with six capacity to the insoluble form with capacity of 3; this bacteria also can remove intracellular accumulation of chromium from the environment (Meybodi and Khorasani 2014).

According to the results obtained by Abyar et al. (2012) *Achromobacter piechaudii* isolated from sediments in Persian Gulf with removal of 65% Cd at 25mg/l concentration after 150min can be used to reduce Cd pollution in aquatic ecosystems.

Shah Alian et al. (2016) showed that Pb adsorption by *Ochrobactrum anthropi* with 84% adsorption rate at 50mg concentration is a suitable option for bioremidation of Pb.

Takeuchi et al. (2007) reported that accumulating bacteria or arsenic-resistant bacteria in aqueous environments such as *Marinomoas communis* has potential for bioremidation of arsenic from polluted aqueous environments.

According to studies conducted by Chitsaz et al. (2012) Sulfate reduction bacteria (SRP) can remove 89.7% of arsenic.

Membrane of *Bacillus subtilis* contains S layer or Slayer Protein that itself contains 20% of proteins of bacteria, which is a considerable amount. The highest amount of heavy metals adsorption in *Bacillus subtilis* is done by this protein (Allievi et al. 2011). Endospore of this bacterium can perform as a vegetative cell in adsorption of heavy metals due to its various layers so that endospore can adsorb heavy metals like vegetative cell of *Bacillus subtilis*. Hence, use pf living cells of this bacterium can remove Pb from the environment even in case of lack of growth and conversion of vegetative cell to endospore in polluted wastewater (Allievi et al. 2011).

According to Khanaferi et al. *Bacillus subtilis* isolated from active sludge of urban wastewater plant is a suitable option for removal of pollutants from aqueous environments due to rapid flocculation under the simple nutritional conditions and ability tp remove 84% Pb from aquatic environment (Khanaferi et al. 2011).

Genetically engineered microorganisms (GEMs) contains external genes that are generated by microorganisms with similar or different species using DNA technology in their genome; these engineered microbes can be used to obtain the proper strain for bioremidation of environment by removing various kinds of pollutions (Dixit et al. 2015).

It has been reported that genetically engineered M109 strain Eschericia coli and *mer A* gene-containing GE *Pseudomonas putida* can remove Hg pollution from soils and sediments effectively (Barkay et al. 2003, Chen and Wilson 1997, Deckwer et al. 2004).

Genetic engineering makes it possible to create engineered bacteria for bioremidation of heavy metals such as As, Cd, Cu, Hg, Ni (Azad et al. 2014, D souza 2001, Verma and Sing 2005).

CONCLUSION

Bioremidation methods for removal of heavy metals from soil and aqueous environments can eliminate constraint of other methods as a cost-effective method. Considering resistance of bacteria against heavy metals and their ability to remove or reduce these elements, they can play an effective role in bioremidation of heavy metals.

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