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Bioremediation strategies for chromium removal: Current research, scale-up approach and future perspectives

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HIGHLIGHTS

- Cr(VI) of industrial effluents impact negatively in human health and environment.
- The removal of Cr(VI) from wastewater requires serious and immediate attention.
- Biological removal of Cr(VI) is a sustainable technology environmentally friendly.
- Cr(VI)-bioremediation strategies are applied in different systems and scales.
- Research is essential to solve the problems associated to the large-scale remediation.

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ABSTRACT

Industrial applications and commercial processes release a lot of chromium into the environment (soil, surface water or atmosphere) and resulting in serious human diseases because of their toxicity. Biological Cr-removal offers an alternative to traditional physic-chemical methods. This is considered as a sustainable technology of lower impact on the environment. Resistant microorganisms (e.g. bacteria, fungi, and algae) have been most extensively studied from this characteristic. Several mechanisms were developed by microorganisms to deal with chromium toxicity. These tools include biotransformation (reduction or oxidation), bioaccumulation and/or biosorption, and are considered as an alternative to remove the heavy metal. The aim of this review is summarizes Cr(VI)-bioremediation technologies oriented on practical applications at larger scale technologies. In the same way, the most relevant results of several investigations focused on process feasibility and the robustness of different systems (reactors and pilot scale) designed for chromium-removal capacity are highlighted.

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1. Introduction

The population growth and different anthropogenic activities have contributed to a worsening of environmental contamination. Industrial effluents are produced by the incorporation of organic and inorganic contaminants, as well as by discharged of heavy metals such as chromium, cooper, cadmium, lead, and selenium. These wastewater containing heavy metals are often discharged into the environment (water, air and soil) without appropriate treatment, resulting in a worldwide severe socio-environmental problem (Gavrilescu, 2004; Wang and Chen, 2006). They are non-degradable toxic pollutants (Modoi et al., 2014; Pavel et al., 2012), thus persistent in nature that accumulates in the food chain, which with time reach detrimental levels in living systems, resulting in several diseases such as irritation and/or cancer in lungs and digestive tract, low growth rates in plants and death of animals (Cheung and Gu, 2007; Orozco et al., 2008), and others health alterations.

Chromium is a geochemical element widely distributed in rocks, minerals soils, and fresh water. The metal present several oxidation states but the more stable forms in the environment are the trivalent [Cr(III)] and hexavalent [Cr(VI)]. Due to their oxidizing nature, Cr(VI) (mainly CrO_4^{2-} at neutral pH or alkaline conditions) is a known mutagen and carcinogen compound to living organisms, including humans. (Fernández et al., 2010; Costa, 2003). This heavy metal has been designated a priority pollutant in many countries and by the United States Environmental Protection Agency-USEPA (Fernández et al., 2009; Juvera-Espinosa et al., 2006; Ksheminska et al., 2003). Studies have provided evidence that Cr(VI) toxicity is due to the fact that metal complexes can easily cross cellular membranes and trigger intracellular Reactive Oxygen Species (ROS) accumulation altering cell structures (Fernández et al., 2009; Morales-Barrera and Cristiani-Urbina, 2006). It has been estimated that Cr(VI) is 100 times more toxic and 1000 times more mutagenic than Cr(III) (Chojnacka, 2010). Instead, Cr(III) is essential to human metabolism, related to maintenance of glucose, cholesterol and triglyceride levels, cellular membrane stability, synthesis and stability of nucleic acids and proteins (Fernández et al., 2014; Frois et al., 2011; Poljsak et al., 2010). Di Bona et al. (2011) recently reported that Cr(III) can no longer be considered as a dietary supplement because rats subjected to a diet with low content of trivalent chromium suffered no adverse consequences when they are compared with rats subjected to a diet with a sufficient dose of Cr(III). However, at high concentrations Cr(III) can complex with organic compounds interfering with metalloenzyme systems (Poljsak et al., 2010; Fernández et al., 2009; Krishna and Philip, 2005), may also cause health problems e.g. lung cancer (Costa, 2003), birth deficiency and the decrease of reproductive health (Marsh and McInerney, 2001).

This heavy metal is frequently discharge into the soil and water from various polluting sources, such as electroplating, wood preservation, leather, mining industries, and others industrial activities (Tekerlekopoulou et al., 2013). The maximum permitted tolerance limits for total Cr into inland surface water is 0.5 mg/L, according to the Environmental Protection Agency (USA) (Tekerlekopoulou et al., 2013; Baral and Engelken, 2002). For that reason, the removal of the metal must be applied effectively and without causing impact on the environment. The most widely used methods are the conventional physicochemical processes such as reverse osmosis, electrochemical process, ion exchange, adsorption on activated carbon, excavation and solidification/stabilization, etc. (Witek-Krowiak, 2013). These technologies reduce the negative metal effect but they present major disadvantages such as generation of toxic waste sludge, high energy requirements or incomplete removal (Bahi et al., 2012). Consequently, the search for cheaper and more effective technologies has become necessary to develop of more economical, safe, and environmentally friendly methods to remove Cr(VI) ions from industrial wastewaters. The potential of adaptation and growth of Cr-resistant microorganisms (e.g. bacteria, fungi, and yeasts) led to hypothesize that biological removal methods would be a sustainable alternative technology of lower impact on the environment. Different microorganisms have been isolated and identified as having the capacity to remove Cr(VI) contamination by different biological methods (biosorption, bioaccumulation, bioreduction). Nowadays, biological treatment of heavy metal containing wastewater by using microorganisms is one of the most active research fields (Fernández et al., 2014).

Considering the socio-environmental impact related to Cr in industrials effluents and the toxic effect for human and animal health, this work summarize and discuss the potentialities of bioremediation of Cr(VI) applied at different scales (bioreactors and pilot scale) to diminish the contents of Cr(VI) until acceptable levels.

2. Microbial mechanism of Cr(VI) resistant

There are a number of autochthonous microorganisms with capability to adapt to and colonize contaminated environments, which are uninhabitable for animals and plants. The isolation of Cr-tolerant strains which naturally inhabit uncontaminated or contaminated environment undergoing purification is important to conduct a future process of bioremediation.

The knowledge about the interaction between microorganisms and heavy metals has an increasing interest. Microbial remediation is defined as the process by which microorganisms are stimulated to rapidly degrade the hazardous contaminants to environmentally safe levels in soil, subsurface materials, water, sludge and residues (Asha and Sandeep, 2013). The study of microbial mechanisms interaction with Cr is of both fundamental and biotechnological interest (Gutiérrez-Corona et al., 2016). Different detoxifying mechanisms developed by these microorganisms include the metal uptake (bioaccumulation or biosorption), and/or the