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Bioremediation of acid mine drainage using algae strains: A review

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A B S T R A C T

Acid mine drainage (AMD) causes massive environmental concerns worldwide. It is highly acidic and contains high levels of heavy metals causing environmental damage. Conventional treatment methods may not be effective for AMD. The need for environmental remediation requires cost effective technologies for efficient removal of heavy metals. In this study, algae based systems were reviewed and analyzed to point out the potentials and gaps for future studies. Algae strains such as *Spirulina* sp., *Chlorella*, *Scenedesmus*, *Cladophora*, *Oscillatoria*, *Anabaena*, *Phaeodactylum tricornutum* have showed the capacity to remove a considerable volume of heavy metals from AMD. They act as "hyper-accumulators" and "hyper-adsorbents" with a high selectivity for different elements. In addition, they generate high alkalinity which is essential for precipitation of heavy metals during treatment. However, algae based methods of abating AMD are not the ultimate solution to the problem and there is room for more studies.

Keywords: Acid mine drainage; Algae strains; Contamination; Heavy metals; Bioremediation

Contents

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1. Introduction

Acidic solutions can be formed by natural decomposition of sulfide materials through oxidative processes in effluent wastewater. The leaching of heavy metal contaminants from within a rock matrix can be a result of high acidity levels of effluent wastewater. These processes can be catalyzed by contact with pre-existing environmental contaminants. These contaminants in very small quantities form activated complexes with various heavy metal atoms encouraging their ionization, dissolution and suspension in the liquid waste medium. These effluents can be released into the environment by spillage, overflow, percolation and intentional discharge. It has adverse effects on environmental health because of the heavy metals pollution downstream from the source.

Regarding acid mine drainage (AMD), the high concentrations of heavy metals cause major environmental concerns characterized by contamination of various ecosystems due to its leaching capacity and the presence of very active bacteria making it self-perpetuating (Kalin et al., 2006). There is a necessity for AMD treatment to prevent disastrous consequences in the environment. Therefore, effective methods of trapping and sequestering heavy metals from effluent to prevent downstream contamination and remediate the local environment are required. Various bioremediation methods based on the ability of plants to take up and accumulate heavy metals were suggested. There are two distinct strategies to remediate the issues regarding AMD treatment. The first is the conventional treatment process in which the effluent is collected then biologically and chemically treated in a centralized wastewater treatment plant. The second involves the channeling of the effluent through natural or constructed wetlands in which microbes or cells such as anaerobic and aerobic microorganisms and various algae strains can be used to treat the wastewater passively. In this study the focus will be on algae based treatment for AMD. An effective treatment for AMD should be self-renewing; the use of algae based treatment is ideal because of its sustainability.

Algae as decontaminating agents offer several advantages including low costs, easy manipulation, non-polluting, relatively simple recovery of the metal contaminants for recycling, and are not a source of secondary waste (Kalin et al., 2006). Conceptually, the algae should grow in the contaminated effluent then the algal biomass and water should be separated and dried to recover the concentrated metals content by conversion to oxides or other recoverable salts. Alternatively, the recovered dry algal biomass can be stored for future use or sequestered. Also, algae biomass can be disposed in municipal waste landfills to reduce its environmental footprint and boost the potential of producing biofuel (Edmundson and Wilkie, 2013).

Phycoremediation is the process of employing macro or microalgae for wastewater treatment. It has many advantages over the conventional methods, which are very costly, energy consuming and generating high amount of sludge hence it is accepted throughout the world (Ghosh and Singh, 2005; Abdel-Raouf et al., 2012). This method involves the use of macro or microalgae for the removal or biotransformation of pollutants, including nutrients and xenobiotics from wastewater (Ahmad et al., 2013). Over the last few decades studies were undertaken to apply microalgae such as *Chlorella*, *Chlamydomonas*, *Spirulina*, *Scendesmus*, *Nostoc* and *Oscillatoria* for wastewater treatment (Dubey et al., 2011; Sharma and Khan, 2013).

The fundamental assumption is that the microalgae are versatile to convert the contaminants into non-hazardous resources, enabling the treated water to be recycled or reused or safely discharged (Rao et al., 2011). This technology is low in cost and it is an effective approach to remove excess nutrients, contaminants in wastewater and generating possibly useful biomass (Sengar et al., 2011). Therefore present investigation focuses on analyzing various species that are capable of removing contaminants from AMD or toxic compounds from acid mine drainage. It also looks at the mechanism of removing contaminants, the operating conditions and the critical aspects of the technology. Also, to clearly describe the effectiveness and potential of algae based technology for removal of contaminants in acid mine drainage.

Today algae based treatment is used in combination with secondary treatment. Microorganisms work in symbiosis with algae cells for an effective treatment. The study will contribute also in emphasizing on the current role of algae in wastewater treatment.

2. Review of acid mine drainage: summary

Although various natural environmental effects contribute to the formation of acids in the environment, AMD as a result of human activities can be attributed in large part to the oxidative decomposition of exposed pyrite (iron sulfide, FeS_2) by water and oxygen as presented in equations (1)–(4):

$$FeS_2 + 7/2O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (1)$$

$$Fe^{2+} + 1/4O_2 + H^+ \rightarrow Fe^{3+} + 1/2H_2O \quad (2)$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ \quad (3)$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (4)$$

The oxidative reaction converts the solid pyrite to dissolved ferrous iron ions (Fe^{2+}) and the equivalent of two units of aqueous sulfuric acid ($2H^+$ ions and $2SO_4^{2-}$ sulfate ions dissolved in the water). The ferrous ions, on exposure to dissolved or atmospheric oxygen, undergo further oxidation to produce ferric ions (Fe^{3+}) which then react directly with pyrite to increase the acid content of the water and the establishment of acidophilic bacteria colonies further promotes the acidification process (Costello, 2003).

Gaikwad and Gupta (2008) associate acid mine drainage, also known as abandoned mine drainage, to the reaction of water and oxygen specifically with coal mining. Water passing through the rocks from mining operations that have been deposited on the surface and the underground voids left behind by mining activities causes the formation of acidic drainage effluents. This occurs by the reaction involving oxygen, water and pyrite sulfidic and non-sulfidic minerals to produce acid sulfate rich wastewater know as AMD. Kuyucak (2002) terms the AMD phenomenon as “acid rock drainage” (ARD) and notes that the same chemical reactions can take place in roads and bridge construction, and in the construction of tunnels through rock formations.

With the formation of net acidity, effluent water becomes increasingly laden with Fe, Mn, Al, Zn, Cu, Ni, Pb, As and Cd as the principle heavy metal contaminants. Ben and Baghour (2013) found that Cd is typically the most mobile and therefore has the highest bioavailability. Furthermore, the presence