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Review

Microbial biotechnology as an emerging industrial wastewater treatment process for arsenic mitigation: A critical review

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A B S T R A C T

Industrial wastewater pollution has become more grievous in the third world countries, where treatment and administration of industrial effluents are not being properly handled. About 80% of wastewater having arsenic (As) contamination are due to impurities in pesticides, chromated copper arsenate (CCA) wood preservatives, municipal solid waste incineration; leather industry; and consumption in the industry. Arsenic is a toxic metalloid, which is considered as a severe menace to the life of plants, animals and humans. Some As species such as As(III) and As(V) cause harmful effects on plants and animals. In order to treat As in industrial wastewater, various conventional methods are being employed. However, these methods face limitations in form of missing technical expertise and low effectiveness. Recently, microbial As remediation of industrial water has been evolved as a promising technology due to its public acceptance and cost effectiveness. The current review, for the first time, comprehensively summarizes the role of microbial remediation of As in industrial wastewater. In contrast to phytoremediation, the goal of using microbes is that dissolved arsenic species are converted microbially to arsine gas which is released into the atmosphere at non-toxic levels (dilution effect). In contrast to phytoremediation where arsenic is accumulated in plant material (waste production), this will not produce any solid or liquid waste - and this is just a key benefit of the microbial approach as the management of solid/liquid arsenic rich waste is a global concern and economic burden; however, it was so far only tested on laboratory scale with exception of biofilms that have been tested on pilot scale. Our review also indicated the huge undervalued potential and environmental friendly solution of microbial remediation of As contaminated industrial wastewater without solid/liquid waste production as conventional technologies do.

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Abbreviations: As, Arsenic; CCA, chromated copper arsenate; -SH, sulfhydryl group; USEPA, United States Environmental Protection Agency.

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1. Introduction

Appropriate treatment of industrial wastewater becomes increasingly essential to: (i) recover freshwater from industrial wastewater for beneficial uses which is an ever increasing imperative due to ever increasing freshwater demand (irrigation water being the largest consumer) due to demographic and economic growth and (ii) reducing environmental impacts (e.g., Maretto et al., 2014; Christóvão et al., 2015; Abourached et al., 2016; Bhuiyan et al., 2016; Ruiz-Rosa et al., 2016). Thereby, the metalloid arsenic (As) is of principal concern, since it is highly toxic to environment and humans and present in many industrial wastewater streams such as those from (i) mining and related activities (ore processing, smelters, etc.); (ii) wood processing industry and wood combustion; (iii) carbon and petroleum exploitation, processing, refining and combustion; (iv) geothermal exploitation; (v) agrochemical industry (e.g., related to impurities in pesticides) and agricultural wastewater due to their applications; (vi) water treatment sludge; and (vi) municipal solid waste incineration (Matera and LeHecho, 2001; Maretto et al., 2014; Woon and Lo, 2014; Bundschuh and Maity, 2015; Ahmad et al., 2016; Chen and Lo, 2016).

Industrial microorganisms are increasingly applied at large scale for production of food and beverages, cosmetics, pharmaceuticals and construction materials and used for energy purposes and treatment of domestic wastewater. They can be produced fast in large quantities and – if needed – their genetic engineering can improve their desired properties. Industrial microbiology provides well-established mature and innovative technologies, which are continuously further developed, and experiences, which can be used for developing and up-scaling industrial-scale applications for treatment of industrial wastewater including those with high arsenic concentrations. The ongoing debate of using genetically modified microbes, in particular if used for food production and processing, needs to be taken into consideration when comparing natural or genetical engineered (GE) microorganisms regarding the removal efficiency of arsenic from water and using this water e.g. for irrigation or artificial groundwater recharge.

To the knowledge of the authors, there is so far no industrial-scale application using microbes for arsenic removal from industrial wastewater and biofilms are the only ones which have been found promising on pilot scale as it also can be recognized from the compilations in Tables 1–3 on As removal from industrial wastewater using bacteria, fungi and biofilms, respectively (and the references therein). However, the results of the laboratory-scale experiments are promising and encourage to develop industrial-scale applications and perform life-cycle assessments showing their economic viability and performance in comparison to conventional technologies for As removal from wastewater where the management of the residual As-rich waste constitutes a key economic burden (e.g., Sullivan et al., 2010).

There is a number of conventional methods to remove As from industrial wastewater (Lata and Samadder, 2016; Mokashi and Paknikar, 2002). The available conventional techniques (physicochemical treatments) include processes that can be used alone or in combination, such as oxidation, coprecipitation and adsorption onto coagulated flocs, lime treatment, and use of ion exchange resins (Litter et al., 2010). Adsorption onto suitable surfaces such as iron oxide (Öztel et al., 2015; Shih et al., 2015), iron oxide coated sand (Yang et al., 2015), manganese-oxide (Yu et al., 2015), magnesite (Masindi and Gitari, 2016) granular-activated carbon (GAC) (Ananta et al., 2015; Podder and Majumder, 2016), zerovalent iron, biochar (Vithanage et al., 2017) and other materials form another As removal option (Dowling et al., 2015). Electrochemical methods and plasmotechnologies (Hilson, 2000) are also applied. Another group of technologies are membrane applications in particular reverse osmosis, electrodialysis, electrodialysis reversal, nanofiltration, as well as new membrane applications such as forward osmosis and membrane distillation (Ahluwalia and Goyal, 2007; Marino and Figoli, 2015) and capillary zone electrophoresis (Harvanová and Bloom, 2015; Mondal et al., 2008b). All of these conventional techniques have the disadvantage that they produce toxic residual waste which requires expensive management (Sullivan et al., 2010), and often have limited efficiency, operational difficulty (e.g. if As is present as neutral As(III) species, a pretreatment to oxidize it to As(V) is required) and high operational cost (Fazi et al., 2015; Litter et al., 2010; Vidali, 2001). Recently, microbial remediation tends to be a promising technology to recover and remediate As in industrial wastewater in an environmentally and economic sound way (Fazi et al., 2015; Finley et al., 2010; Ibrahim and Mutawie, 2013). Such microorganisms are termed as "eco-friendly nano-factories" by some environmentalist (Arya, 2010; Sinha et al., 2010).

This paper provides a critical review of using different microorganisms (bacteria, fungi etc.) and compares their suitability for removal of inorganic As(III) and As(V) species from industrial wastewater. Beneath a compilation of the state-of-the-art knowledge of the different groups of microbes and a comparison of them regarding suitability for As removal (i.e., removal efficiency, possible As concentration range in raw water, easiness for upscaling from laboratory to industrial scale, technical complexity and maintenance needs), the research gaps and the needs for further research and development (R&D) are discussed.

2. Water and wastewater treatment by microorganisms

Microorganisms play a pivotal role in the biochemical cycle of As, through its conversion to species with different solubility, mobility, bioavailability and toxicity (Silver and Phung, 2005). A variety of mechanisms exists for the removal of heavy metals and metalloids from aqueous solution by bacteria, fungi, ciliates, algae, mosses, macrophytes and higher plants (Clares et al., 2015; Gupta et al., 2015; Rehman et al., 2010; Umar et al., 2015; Yargıç et al., 2015).

Various microbial methods have been used to remediate As in industrial wastewater which include biovolatilization, biosorption, bioaccumulation, methylation via mobilization, dissimilatory reduction, adsorption, metal precipitation and co-precipitation (Paul et al., 2015; Roy et al., 2015; Stolz et al., 2006). Furthermore, metal-organic complexion, metal ligand degradation, intracellular