Removal of Arsenic from Wastewater through Bacteria

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ARTICLE INFO

ABSTRACT

Arsenic contamination in wastewater is a global dilemma disturbing millions of the peoples. Arsenic is a toxic metalloid that poses a significant health risk when consumed in drinking water. One approach to remove arsenic from wastewater is through the use of bacteria. Several bacteria species have been identified as potential candidates for arsenic removal. These bacteria can oxidize or reduce arsenic, converting it into less toxic forms or sequestering it. This review summarizes recent studies on by using bacteria on the elimination of arsenic from wastewater. The mechanisms of arsenic removal, factors affecting bacterial activity, and here we discussed wastewater treatment by the prospective of bacterial systems for large-scale treatment. The review concludes with a discussion of prospect examine directions and confronts in the progress of bacterial systems for arsenic removal from wastewater. Overall, the utilize of bacteria for arsenic removal shows promise and warrants further investigation as a potential solution for arsenic contamination in wastewater.

INTRODUCTION

Arsenic pollution of water sources has become a global concern, through millions of peoples
worldwide at danger of exposure toward this toxic substance. Arsenic is a naturally stirring constituent that is released into the environment through various industrial and agricultural activities. The most significant source of arsenic in water sources is from underground aquifers, which are often used for drinking water in developing countries. A range of health problems caused by Chronic exposure to arsenic, including cancer, skin lesions, and heart disease.\cite{1}

Arsenic belongs to the same family as nitrogen, phosphorus, antimony, and bismuth and has diverse valence states (-3, 0, +3, and +5) based on environmental conditions. In anaerobic ground water As(III) is present, while in soil As(V) is the most common form. Both varieties exist in terrestrial and aquatic environments, and the reduction of As(V) toward As(III) can lead to water contamination. The occurrence of As(-3) and As(0) is rare due to their high reactivity and volatility.\cite{2} By local biological features and chemical surroundings the concentration of arsenic in aquifers is determined. Compared to surface water Groundwater tends to have upper levels of arsenic. Arsenic is more soluble in groundwater, particularly when it is there in the variety of As(III). Arsenic meditations are naturally moderate (0.2-2 mg/L) in surface waters. On the other hand, in specific environments such as geothermal and excavation drainage systems, arsenic levels can be as high as 1000 mg/L.\cite{3}

Conventional physico-chemical methods have been exploiting to treat arsenic-contaminated water. On the other hand, these methods can be costly, produce large amounts of sludge, and may not be sustainable in the long run.\cite{4} As a result, there has been growing interest in developing biological treatment methods for removing arsenic from wastewater.

Biological treatment methods use living organisms to remove contaminants from wastewater. Bacteria, in particular, have shown significant possible in eliminating arsenic from contaminated water. Bacteria are capable of transforming or adsorbing arsenic through a variety of mechanisms, including oxidation, reduction, methylation, and adsorption onto their cell walls.\cite{5} The main two mechanisms by which bacteria can transform or adsorb arsenic are oxidation and reduction. Oxidation involves the conversion of arsenic in its more lethal form (As III) to a less noxious form (As V) that can be easily removed, while reduction involves the alteration of As V to As III. Some bacterial strains can convert toxic forms of arsenic into less harmful forms, while others can immobilize arsenic through adsorption onto their cell walls.\cite{6} Bacterial treatment of wastewater is often more cost-effective and sustainable than conventional methods, making it an attractive alternative for developing countries and other regions facing arsenic contamination.\cite{7}

Several bacterial strains have been deliberated for their capability to remove arsenic from contaminated water. These include *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Shewanella sp.*, and *Rhodopseudomonas palustris*, among others.\cite{8} These bacteria have shown varying degrees of effectiveness in removing arsenic from wastewater, with removal rates ranging from 70% to 99%. Bacteria, in particular, have shown significant potential in removing arsenic from contaminated water. Several factors affect bacterial performance in arsenic removal, including the pH, temperature, and the presence of other chemicals in the water source. The effectiveness of bacterial arsenic removal can furthermore be impacted by the presence of heavy metals, which can affect bacterial growth and activity.\cite{9}

This evaluation article aims to give an overview of the function of bacteria in the removal of
arsenic from wastewater. It covers the mechanisms by which bacteria can transform or adsorb arsenic, the factors that affect bacterial performance in arsenic removal, and the various bacterial strains that have been studied for this purpose. The article concludes by discussing the challenges and opportunities for optimizing bacterial treatment for arsenic removal and developing cost-effective and scalable systems for implementation in real-world settings.

**Biologically exclusion of arsenic from waste water**

Biological exclusion of arsenic from wastewater refers to the use of living organisms, such as microorganisms or plants, to remove or reduce the concentration of arsenic contaminants in wastewater. This approach harnesses the natural abilities of certain organisms to interact with and transform arsenic, thereby facilitating its removal from water sources.

For industrial-scale plants, a wide range of arsenic deletion technologies are accessible, including reverse osmosis, anion interchange, activated alumina, modified lime softening, modified coagulation/filtration, and changed oxidation/filtration. The effectiveness of these skills depends on a number of variables, including the maximum pollution level, the co-occurrence of solutes, the superiority of the source water, and operating and maintenance expenses. According to a cost comparison by Mondal et al, activated alumina sorbents are the least expensive removal process with the maximum efficiency (>95% deletion of arsenic), while lime-softening expertise and coagulation/filtration are the least expensive with the lowest proficiency (90% deletion of arsenic). However, iron-based sorbents are still expensive for developing countries to utilize since they cannot be recycled. Therefore, research is still ongoing to find accessible and efficient substitutes for sorbents or sorbents with a surface coating.

In addition, conventional treatment technologies may not effectively remove together As(III) and As(V) forms, due to its negatively charged facade As(III) being particularly difficult for removal. The recent arsenic consumption water average of 10 µg/l has led to a significant requirement for oxidation knowledge that can convert As(III) into As(V) preceding to removal. As a promising solution to these challenges organic water treatment methods have emerged, with expanding research consideration given to the utilization of regular consortia, unadulterated societies of arsenic-defiant microorganisms, and iron-and manganese-oxidizing microbes to change or potentially catch arsenic varieties indirectly.

A new technology for removing arsenic from water involves the use of biocolumn reactors. These reactors use immobilized bacterial cells that have the ability to adsorb arsenic. For the use of arsenic removal from drinking water a biocomposite composed of grains of cement smeared with cysts of *Azotobacter* has been developed. This biocomposite had the option to eliminate around 96% of arsenic because of the collaboration of polysaccharides and different macromolecules with arsenic. Another review used immobilized cells of *Ralstoniaeutropha* on a granular, enacted carbon bed in a segment reactor to eliminate arsenic from an engineered modern effluent. The cells had the option to catch both As(III) and As(V) after an underlying phase of variation and bio-film arrangement.

Bio-evacuation cycles can eliminate arsenic throughout the immediate adsorption of microbial biomass or through adsorption and co precipitation with biogenic iron or manganese hydroxides. Organic cycles can likewise be utilized for the oxidation and expulsion of disintegrated iron and manganese, which can be a proficient means for the synchronous
Evacuation of arsenic and iron. Iron oxidation brings about the development of a combination of ineffectively requested iron oxides with natural matter that can eliminate arsenic through direct adsorption or co precipitation. As (III) can likewise be oxidized by iron-oxidizing microbes Gallionella farruginea and Leptothrixochraceato further improve large removal proficiency. In a trial, scientists researched the evacuation of arsenic during natural iron oxidation and found that iron oxides saved in the channel medium, alongside iron-oxidizing microscopic organisms, gave a positive climate to arsenic expulsion. Thus, arsenic expulsion expanded up to 95% even with starting arsenic fixations up to 200 µg/l. 

Before the discovery of Desulfosporosinusauripigmenti, a bacterium that can respire As(V) and sulfur, resulting in the synthesis of arsenic trisulfide (As2S3) and auripigment, it was thought that As(V) reducers would increase the mobility of arsenic. According to recent studies, the anaerobic bacterium Shewanella sp. strain HN-41 can produce photoactive As-S (realgar) nanotubes and convert As(V) to As(III) for detoxification. It employs lactate as an electron donor and S2O32- as an electron acceptor. The efficiency of As(III)-oxidizing microorganisms connected to immobilized equipment has been assessed in a number of recent research. For instance, Ito et al. carried out a study utilizing a bioreactor holding immobilized Ensiferadhaerens cells to assess the strain's capacity to oxidize As(III) on polyvinyl alcohol gel droplets in artificial groundwater comprising 1 mg/l of As(III). According to the study's findings, As(III) completely oxidized to As(V) during the trial, yielding a removal effectiveness of 90%.

In order to create a mathematical model for arsenic exclusion utilizing packed-bed sections in a continuous pour reactor with Rhodococcus equi cells stopped on rice husks, Bag et al. led a review to look at the As(III)-oxidizing presentation of the reactor. With arsenic absorption fluctuating from 50 to 100 ppb, they employed purposefully and naturally agitated water. With a maximum As(III) exclusion efficacy of 95%, the study found that the virtual results were pretty close to the experimental data. It was demonstrated that the cells could detoxify the fictitious arsenic water. Numerous investigations have shown that As(III) oxidation can occur in both pure cultures and bacterial consortia. These investigations looked into the creation and function of an As(III)-oxidizing biofilm created in a bioreactor by the CAsO1 collaboration using pozzolana as a growth support. Michel and colleagues discovered that the biofilm structure acted as a physical barrier that constrained As(III) entrance to sessile cells and prevented the development of As(III) oxidase activity in both the consortium and an unpolluted culture of T. arsenivorans. They proposed that the reactor's efficiency may be improved by streamlining and controlling a number of variables, such as hotness and the development of extracellular polymeric materials, that have an impact on how biofilms are structured. Michon and colleagues demonstrated that the CAsO1 consortium could oxidize As(III) not only in the'mg/l substantial degree' but also in the 'g/l significant magnitude' focal size.

Adsorbents such as iron oxides, activated alumina, and activated carbon have been shown to effectively eliminate arsenic from contaminated water, and when combined with microorganisms, can lead to even higher removal efficiencies. For example, the use of iron oxide-coated sand and the bacterium Pseudomonas stutzeri has been shown to remove up to 98% of arsenic from impure groundwater. The use of activated alumina and the bacterium Bacillus subtilis has also been publicized to be efficient in eradicating of arsenic from infected
water [50]. In addition, the use of activated carbon and microbial consortia has been shown to remove both arsenic and other toxic impurities from wastewater. [51] Various researchers have explored the use of sorbents to eliminate As(V) produced as a consequence of the biological oxidation of As(III). One-step and two-step procedure of combining natural oxidation and chemical removal on top of man-made sorbents have been studied. In solitary of the earliest experiments in this area, Lièvremont et al. discovered that kutnahorite and chabazite, two mineral segments, exhibited diverse capabilities in adsorbing arsenic post-biological oxidation and accomplishing abiotic oxidation. [23] Their findings revealed that the bacterial strain examined rapidly oxidized As(III) in the existence of chabazite at high arsenic concentrations, while kutnahorite effectively removed As(V). Thus, they proposed a two-phase detoxification method.

Ike et al. demonstrated that using a assorted culture of different As(III) oxidizers greatly improved arsenic removal by activated alumina through microorganisms oxidation of As(III) to As(V). Their findings suggested that performing the two procedures successively was necessary to achieve optimal conditions in each step. [24]

In a more recent study, Wan et al. established two reactors - one containing T. arsenivorans cells and sand, and the extra filled through zero-valent iron (ZVI). [25] The experiment was flourishing in terms of natural As(III) oxidation, and ZVI enhanced chemical arsenic exclusion, although a reduction in adsorption capacity was experimented throughout the peak of organic oxidation. This decrease may have been caused by biofilm configuration on the ZVI facade and alteration in the physicochemical situation.

Because of their extracellular polymeric materials and reactive microbial surfaces, microscopic organisms that can oxidize arsenic may reduce the ability of sorbents to retain arsenic. Huang et al.’s work focused on the important interactions amongst phosphate and carboxylate groups on Shewanella putrefaciens’ cell surface. Arsenic activation resulted from As(V) being adsorbed onto goethite and ferrihydrite. [26] Kim et al. discovered that a combination of E. coli, Enter and Bacillus subtilis had no effect on removing arsenic when using iron-impregnated granular-activated carbon. [27]

**Bacterial Potential for Large Scale Wastewater Treatment**

Bacterial systems have significant prospective for huge amount of wastewater treatment because of their capability to remove an extensive variety of contaminants, their low operating costs, and their minimal environmental impact. In contrast to conventional treatment methods, which often rely on chemical and physical processes, bacterial systems use biologically occurring bacteria to break down and eliminate contaminants from wastewater. [28]

One of the primary recompense of bacterial systems is their capability to remove a broad range of contaminants, including organic matter, nutrients, and toxic compounds. Bacteria play a important role in the breakdown and removal of these contaminants through processes such as aerobic and anaerobic digestion, nitrification, denitrification, and phosphorus removal. This ability to remove a broad range of contaminants makes bacterial systems highly versatile and effective for treating a variety of wastewater streams. [29,30]
Another advantage of bacterial systems is their low operating costs. Compared to conventional treatment methods, which often require significant energy inputs and chemical dosing, bacterial systems operate at low energy and chemical costs. This is because bacteria use naturally occurring processes to break down and remove contaminants from wastewater, requiring only minimal inputs to maintain optimal conditions for bacterial growth and metabolism.\[31,32,33\] In addition to their low operating costs, bacterial systems also have minimal environmental impact. Unlike conventional treatment methods, which often generate significant amounts of sludge and other waste products, bacterial systems produce minimal waste and have minimal environmental footprint. This makes them highly sustainable and suitable for large-scale implementation.\[28,34\]

Despite these advantages, there are also some challenges to the implementation of bacterial systems for large-scale wastewater treatment. These include the need for suitable bacterial strains, the development of efficient and cost-effective production and immobilization methods, and the optimization of operating conditions. However, with ongoing research and development, these challenges can be overcome, and bacterial systems can become an increasingly viable option for large-scale wastewater treatment.\[35,36,37\]

In conclusion, bacterial systems have significant potential for large-scale wastewater treatment due to their capability to remove a broad range of contaminants, their low operating costs, and their minimal environmental impact. While there are some challenges to their implementation, ongoing research and development are helping to overcome these challenges and make bacterial systems an increasingly attractive option for large-scale wastewater treatment.

**FACTORS AFFECTING BACTERIAL ACTIVITY**

Bacterial activity in wastewater treatment systems can be influenced by numerous factors, including pH, substrate availability, temperature, and the presence of inhibitors such as heavy metals and toxic natural compounds. Understanding these factors and their effects on bacterial activity is important for the victorious implementation of bacterial systems for large-scale wastewater treatment.\[38,39\]

pH is an important factor that affects bacterial activity in wastewater treatment. Bacterial activity is optimal within a narrow pH range, typically between 6.5 and 8.5. Changes in pH outside this range can result in decreased bacterial activity and reduced treatment efficiency. Therefore, maintaining optimal pH levels is critical for maximizing bacterial activity and ensuring efficient wastewater treatment.\[40\]

Temperature is another critical factor that influences bacterial activity. Bacterial activity is typically highest at temperatures between 20 and 35°C, with optimal performance observed at around 30°C. Temperatures outside this range can lead to reduced bacterial activity and treatment efficiency. Maintaining appropriate temperatures is, therefore, essential for achieving optimal bacterial activity and efficient wastewater treatment.\[41,42\]

The availability of substrates is another key factor that can impact bacterial activity in wastewater treatment systems. Bacterial activity is directly proportional to the availability of substrates, including organic matter, nitrogen, and phosphorus. Adequate substrate availability is necessary to support bacterial growth and metabolism, and to ensure optimal treatment efficiency.\[43,44,45\]
The presence of inhibitors such as heavy metals and toxic organic compounds can significantly impact bacterial activity in wastewater treatment systems. Heavy metals can interfere with bacterial metabolism, leading to reduced activity and treatment efficiency. Similarly, toxic organic compounds can inhibit bacterial growth and metabolism, leading to decreased treatment efficiency. Therefore, strategies to mitigate the effects of inhibitors, such as the use of microbial consortia, microbial adaptation, and the optimization of operating conditions, are critical for ensuring optimal bacterial activity and efficient wastewater treatment.\[46,47\]

The prospective of bacterial systems for large-scale wastewater treatment depends on a number of factors, including the accessibility of suitable bacterial strains, the development of cost-effective and efficient production and immobilization methods, and the optimization of operating conditions. Bacterial systems have several compensation over predictable treatment techniques, including their capability to remove a broad range of contaminants, their low operating costs, and their minimal environmental impact. However, to be effective for large-scale wastewater treatment, bacterial systems must be optimized to ensure high treatment efficiency, long-term stability, and low maintenance costs.\[35,43,48\]

In conclusion, several factors influence bacterial activity in wastewater treatment systems, including pH, temperature, substrate availability, and the presence of inhibitors. The prospective of bacterial systems for large-scale wastewater treatment depends on the optimization of these factors, as well as the development of cost-effective and efficient production and immobilization methods.

**Challenges and Future Research Direction**

One of the primary challenges in the use of bacterial systems for arsenic removal is the maintenance of bacterial activity in the existence of high applications of arsenic. The occurrence of arsenic can lead to bacterial inhibition and cell damage, thereby reducing the effectiveness of the treatment system. Researchers are currently exploring various strategies to enhance the tolerance of bacterial strains to arsenic, such as the use of microbial consortia, genetic engineering, and microbial adaptation. Another significant challenge is the development of cost-effective and well-organized methods for the production and immobilization of bacterial strains for use in arsenic removal. The production of bacterial strains in large quantities and their immobilization on suitable carriers or substrates can significantly impact the overall efficiency and sustainability of the treatment system.

Furthermore, there is a need to investigate the potential impacts of bacterial systems on the surroundings and persons health. Studies have exposed that bacterial systems can release toxic metabolites, and the use of genetically modified bacterial strains can pose risks to the environment and human health. Therefore, the development of safe and sustainable bacterial systems for arsenic removal requires a comprehensive understanding of the potential environmental and health impacts of these systems.

Finally, there is a need for further research to optimize the performance of bacterial systems for arsenic removal. This includes the exploration of suitable bacterial strains, the optimization of operating conditions such as pH, temperature, and hydraulic retention time, and the evaluation of the long-term stability and efficiency of the treatment system. In conclusion, the development of bacterial systems for arsenic removal from wastewater holds significant
promise as a sustainable and eco-friendly approach to address arsenic contamination. However, several challenges and research directions need to be addressed to optimize the efficiency, sustainability, and safety of these systems.

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