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Sulfate-Reducing Bacteria in Industrial Waste Management: A Comprehensive Review

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ABSTRACT

In this extensive review, we delve into the crucial role played by sulfate-reducing bacteria (SRB) in tackling the formidable environmental challenges presented by industrial wastes. The spotlight is on the diverse applications of SRB, their nutritional aspects, cultivation methods, and their promising potential in simultaneously addressing the treatment of metals and sulfates. This comprehensive exploration aims to shed light on the multifaceted contributions of SRB to industrial waste management, offering insights that may pave the way for sustainable and effective environmental remediation strategies.

Keywords: Sulfate-Reducing Bacteria, Industrial Waste Management, Metals, Sulfates, Environmental Remediation.

1. Introduction

The industrial sector, serving as a cornerstone for meeting daily necessities, plays a pivotal role in shaping our way of life. However, this essential sector also bears the responsibility for a significant environmental footprint, contributing to pollution in the forms of air, water, and soil contamination. The repercussions of industrial activities, especially the generation of wastes laden with toxic substances, pose a looming threat to environmental sustainability. This dire situation calls for immediate and effective attention to the development of robust remediation strategies (Govindarajalu 2003; Adebisi and Fayemiwo 2011).

Industrial activities, encompassing a diverse range of processes, are integral to modern life, providing goods and services that meet the demands of a growing global population. From manufacturing to energy production, the industrial sector's outputs are deeply intertwined with various aspects of our daily lives. However, this symbiotic relationship comes at a cost – the inadvertent release of pollutants into the air, water, and soil (Govindarajalu 2003).

The pollutants discharged from industrial processes carry a hazardous payload, often laden with toxic substances that have the potential to inflict severe harm on the environment. These pollutants, if left unchecked, can contribute significantly to environmental degradation, posing threats to ecosystems, wildlife, and, ultimately, human health. Recognizing the urgency of this situation, it becomes imperative to focus on the development and implementation of effective remediation strategies.

The need for urgent attention to environmental remediation is underscored by the growing body of evidence highlighting the adverse impacts of industrial pollution. Scientific studies, such as those by Govindarajalu in 2003 and Adebisi and Fayemiwo in 2011, have brought to light the far-reaching consequences of industrial waste on ecological balance and public well-being. This comprehensive review aims to delve into one specific facet of environmental remediation – the role of Sulfate-Reducing Bacteria (SRB) in managing industrial waste. By examining the applications, challenges, and potential innovations related to SRB, we aim to contribute to the ongoing discourse on sustainable industrial practices and waste management.

2. Acid Mine Tailings Wastes (AMTW)

AMTW, originating from mined rocks, pose environmental challenges due to their acidity and heavy metal content. Reactive minerals exposed during excavation lead to acid mine production, accelerated by naturally occurring bacteria. Acidophilic iron-oxidizing bacteria play a crucial role in acid mine drainage generation. AMTW toxicity arises from low pH and heavy metal content, impacting ecosystems and causing health issues (Johnson 2000).

3. Bioremediation of AMTW Using SRB

Conventional treatments for AMTW involve adding alkaline materials, but these methods have drawbacks. Bioremediation, particularly using SRB, offers a promising and economically viable alternative. SRB catalyze the reduction of sulfate to sulfide, selectively removing toxic metals and generating alkalinity. This sustainable approach involves enhancing microbial capabilities to neutralize acidity and immobilize metals, making it environmentally friendly and cost-effective (Johnson 2000).

4. Environmental Concerns and Remediation

The perpetual generation of industrial wastes raises concerns for human health and the environment. The review highlights the significance of an economical bioremediation strategy, emphasizing the synchronous treatment of metals, sulfates, and agro-industrial or hydrocarbon wastes from various industries (Idris et al. 2007).

5. Metal Pollutants and Health Effects

Heavy metal pollution poses global concerns, with sewage water and industrial sources contributing metals like zinc, iron, copper, lead, and cadmium. Health effects of common heavy metals, including aluminum, chromium, manganese, and mercury, necessitate urgent remediation (Armitage et al. 2007; Idris et al. 2007).

6. Sulfates and Industrial Effluents

Sulfates found in industrial effluents pose challenges, leading to acidogenesis, metal corrosion, and toxicological effects. The intrusion of sulfates from various industrial processes can impact both the environment and human health (Boshoff et al. 2004; Lin and Hsiu 1997; Muyzer and Stams 2008).

7. Remediation Strategies

The necessity of treating metals and sulfates before discharging industrial effluents into the environment is discussed. While traditional physicochemical methods have been employed, biological methods, including bioremediation, phenolics modern pathways are the present more cost-effective and environmentally friendly alternative (Malik 2004; Gillespie and Philp 2013, Wagay et al., 2023).

8. Role of SRB in Bioremediation

SRB emerge as pivotal players in the remediation process, offering a sustainable solution to the problems of metals and sulfate toxicity. The paper introduces the concept of biosulfidogenesis, highlighting the diversity, ecology, and biotechnology of SRB and their versatility in various environments and various phytochemicals procesese (Muyzer and Stams 2008, Khan *et al.,* 2023).

9. Nutritional Aspects and Cultivation of SRB

The nutritional aspects of SRB, their diverse metabolism, and cultivation methods using different environmental contaminants as growth substrates are discussed. SRB offer a potential avenue for sustainable waste management (Idris et al. 2007).

10. Applications of SRB

The utilization of Sulfate-Reducing Bacteria (SRB) for the treatment of industrial wastewater has garnered significant interest. Numerous studies have been conducted to explore the applications of SRB in treating both simulated and real wastewaters contaminated with a variety of pollutants (Hussain and Qazi, 2016). Recent advancements have demonstrated the efficacy of SRB in treating diverse environmental contaminants, including metals, metalloids, sulfates, methane, and various hydrocarbons (Battaglia-Brunet et al., 2012; Altun et al., 2014).

However, the majority of these investigations were carried out on a laboratory scale, and there is a dearth of data on the commercial-scale applications of SRB. Only two patented technological applications, based on microbially mediated sulfate reduction in bioreactor systems, have been developed and operated as pilot-, demonstration-, and full-scale plants for treating acidic wastewater from metal mines (Johnson, 2000). These technologies are known as Thiopaq® by Paques, The Netherlands (Boonstra et al., 1999), and BioSulphide® by BioteQ, Canada (Ashe et al., 2008).

The main challenge hindering the practical application of SRB on a commercial scale may be the uncontrolled generation of hydrogen sulfide (H2S) exhaust. As noted by Martins et al. (2009), additionally produced H2S (unreacted) easily escapes as a gas, with some of it inaccessible to the pollutants. This hinders the quantitative treatment of pollutants and may pose severe environmental impacts. To address this issue, optimization of sulfidogenesis and waste treatment within well-designed bioreactors is essential, allowing for maximum contact area and time for H2S and waste(s) to react (Hussain and Qazi, 2016, Jeba et al., 2022). The control of H2S exhaust can be achieved by closing the entire remedial setup, and some form of bio/technical control of unwanted H2S is recommended to make the commercial utility of SRB feasible.

11. Concomitant Treatment of Metals and Sulfates

Addressing the need for concomitant treatment, the review proposes a biphasic model utilizing H2S exhaust from sewage effluents by sulfidogenic bacteria to precipitate metals from industrial effluents. The importance of metal-resistant and heterotrophic sulfidogens in developing single-chambered bioremediation processes is highlighted (Boonstra et al., 1999, Archana et al., 2023).

12. Conclusion

This comprehensive review underscores the importance of sulfate-reducing bacteria in the concomitant remediation of metal and sulfate pollutants, presenting a sustainable and economical approach for environmental protection. The proposed model and insights contribute to advancing bioremediation strategies, especially in regions facing economic constraints.

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