ISSN: 2710-0170

Overview of Research on Bisphenol A Removal from Mine Water

Sen Wang, Siao Zhang, Hao Wang*

North China University of Science and Technology, Tangshan Hebei, 063210, China

Abstract

The pollution of bisphenol A (BPA) in mine water has become increasingly prominent, posing serious threats to ecosystems and human health, while also constraining the reuse of water resources in mining areas. Microbial fuel cell (MFC) technology, as an innovative green approach that combines pollutant degradation with energy recovery, demonstrates significant potential in treating refractory organic compounds and heavy metals. This article provides a systematic review of the advantages of MFC technology in removing BPA from mine water, with a focus on innovative designs such as photocatalytically assisted anodes (e.g., TiO_2/carbon nanotube composites), stacked MFC configurations, and multiple-anode shared-cathode architectures, which enhance pollutant removal efficiency and power output. Studies indicate that MFC systems can efficiently degrade BPA and remove heavy metals (such as Fe, Mn, Zn) through synergistic microbial metabolism and electrochemical processes, while simultaneously converting chemical energy into electricity, aligning with national strategies for renewable energy development. Although challenges related to cost and operational stability remain for large-scale applications, MFC technology holds broad prospects for environmental remediation and resource recovery in mining areas. Future efforts should focus on optimizing reactor structures, electrode materials, and operational strategies to advance the engineering application of this technology.

Keywords

Bisphenol A (BPA), Microbial fuel cell (MFC), Photocatalysis, TiO_2.

1. Introduction

Over the past century, the extensive global use of fossil fuels has significantly driven industrial development and economic progress. However, this has also led to the massive consumption of non-renewable energy resources and left behind numerous environmental issues due to large-scale mineral extraction. With economic development, nations, after achieving higher economic levels, have placed greater emphasis on addressing these legacy environmental problems and issues related to energy recycling and reuse. According to Article 4, Chapter I of the Renewable Energy Law of the People's Republic of China: The State lists the development and utilization of renewable energy as a priority area for energy development, promotes the establishment and development of the renewable energy market by formulating total targets for the development and utilization of renewable energy and adopting corresponding measures. The State encourages economic entities of various ownerships to participate in the development and utilization of renewable energy and protects the legal rights and interests of renewable energy developers and utilizers in accordance with the law. This underscores the importance of energy regeneration for national development. Extracting energy from inorganic or organic substances remains the primary method of energy acquisition. Currently, the burgeoning development of Microbial Fuel Cells (MFCs) offers a new pathway for energy acquisition. MFCs can directly convert chemical energy into electrical energy while removing specific components. In MFCs, microorganisms oxidize organic matter, producing protons and electrons; the migration of these protons and electrons through an external circuit generates electricity. The large-scale

ISSN: 2710-0170

production and frequent use of Bisphenol A (BPA) lead to its continuous release and widespread distribution in the natural environment. Because bisphenols tend to accumulate in aquatic organisms and cause biomagnification in the surface water food chain, pollution of surface water bodies by bisphenols has garnered widespread attention. The GB 5749-2022 "Standards for Drinking Water Quality" also explicitly lists BPA as a reference indicator for drinking water safety, stipulating that the limit for BPA must not exceed 0.01 mg/L. BPA enters the environment from wastewater, pollutants, sediments, surface water, and groundwater. BPA has been frequently detected in nonferrous metal mine water in northern China. BPA poses environmental and health hazards to aquatic systems, affecting ecosystems and human health, severely impacts the safety of the water cycle process, and presents significant obstacles to mine site remediation and water resource reuse. This study plans to create a new configuration microbial fuel cell system, utilizing an anode electrode composed of TiO_2 and carbon nanotubes for photocatalytically-assisted pollutant removal, and employing the combined action of microorganisms and electrochemistry within the fuel cell to target BPA and heavy metals (Fe, Mn, Zn) in mine water. Analysis will be conducted based on electrochemical characteristic parameters, microbial indicators, and conventional indicators (changes in pollutant concentration, changes in various ion concentrations) generated during experiments. Research on this issue is beneficial for the positive development of microbial fuel cells and is of great significance for the removal of BPA and heavy metals from mine water.

2. Bisphenol A in Mine Water

Bisphenol A [2,2-bis(4-hydroxyphenyl)propane; abbreviation: BPA] is an endocrine-disrupting compound with the molecular formula C15H16O2, widely used in various polymer materials, fine chemicals, and manufacturing. Since the 1950s, BPA has been primarily used in industrial activities producing polymer materials such as epoxy resins, polycarbonates, and polysulfone resins. These polymer materials are, in turn, widely used as raw materials for manufacturing industrial products like thermal paper, food containers, flame retardants, building materials, electronic products, and medical equipment. Due to the extensive use of these products, BPA has become one of the most highly produced chemicals in the world [4]. The large-scale production and frequent use of BPA lead to its continuous release and widespread distribution in the natural environment. Because bisphenols tend to accumulate in aquatic organisms and cause biomagnification in the surface water food chain, pollution of surface water bodies by bisphenols has attracted widespread attention. BPA enters the environment from wastewater, pollutants, sediments, surface water, and groundwater [5]. BPA has been frequently detected in nonferrous metal mine water in northern China. BPA causes environmental and health hazards to aquatic systems, affecting ecosystems and human health. The enrichment of BPA in mine water is mainly controlled by climatic conditions, rock dissolution, and human activities [6]. With the increasing development of nonferrous metal mining, in the horizontal direction, the concentration of BPA gradually increases along the groundwater flow path from the recharge area through the runoff area to the discharge area. In the vertical direction, due to the influence of evaporation, the BPA concentration in the shallow water zone gradually decreases with increasing depth [7]. Nonferrous metal mining alters the original inputs, outputs, and groundwater runoff of the hydrological system, leading to stronger hydraulic connections between related aquifers and more intense water-rock interactions. This also promotes the re-release of BPA into mine water. The water-rock interaction process involves many physical and chemical reaction processes, affecting both mine water quality and the coal or rock mass [8]. Mine water quality is generally neutral or slightly alkaline [9], with high content of ions like lead and cadmium, high hardness, and high salinity. If discharged directly without treatment, mine water can cause various harms to the environment and human health: Mine water may contain suspended solids, heavy metals, minerals, and other harmful chemicals. If these

ISSN: 2710-0170

substances are discharged directly into water bodies without treatment, they can cause water pollution, impair water quality, and disrupt ecological balance. Nutrients such as nitrogen and phosphorus in mine water, if discharged into water bodies, can cause excessive growth of algae and other aquatic plants, leading to eutrophication and damaging aquatic ecosystems. Harmful substances in mine water, such as heavy metals and toxic chemicals, can accumulate through the food chain and may ultimately affect human health. Long-term intake of these harmful substances can lead to various health problems, including liver and kidney damage, neurological disorders, and cancer. Acidic mine water is highly corrosive and can corrode delivery pipelines and equipment, causing economic losses and safety hazards. The discharge of large quantities of untreated mine water reduces available clean water resources, affecting the sustainable use of water resources. Mine water has a high salt content and a bitter taste, hence it is also called brackish water. The key process for treating mine water containing lead and cadmium is desalination. Current treatment processes include distillation, ion exchange, membrane separation, and biological treatment. Among these, distillation requires consuming large amounts of thermal energy; ion exchange is suitable for salinity not exceeding 500 mg/L; membrane separation is prone to membrane fouling, increasing experimental costs [10, 11]. Therefore, these methods are constrained by specific conditions and also have issues in terms of cost, operational efficiency, and energy saving. In summary, MFCs can convert BPA into low-toxicity or harmless substances through microbial metabolic activities, effectively reducing environmental accumulation. As a novel wastewater treatment technology, MFCs can degrade BPA while also recovering chemical energy, converting it into electrical energy, achieving waste resource utilization, and promoting sustainable energy development. The environmentally friendly characteristics of MFCs mean they do not produce secondary pollution when treating BPA, reducing the environmental burden. Furthermore, MFCs can improve the biodegradability of BPA and be integrated with other water treatment technologies to form efficient treatment systems. In conclusion, MFC technology plays an important role in reducing the environmental and health risks of BPA, promoting energy recovery, and environmental protection.

Microbial fuel cells are a technology that has received widespread attention in recent years. Microbial fuel cells are based on bioelectrochemical principles, converting chemical energy in solutions into electrical energy. While generating electricity, they can also treat high-concentration pollutants in wastewater, making them a clean and efficient water treatment technology. This project will use microbial fuel cells as a basis to treat mine water, utilizing microbial decomposition and membrane separation to remove acidic salts and various heavy metal ions from the water, generate electricity, increase energy utilization efficiency, and conserve resources.

Based on research on BPA, it has been found that compared to traditional wastewater treatment methods (such as biological treatment, adsorption, ozonation, and oxidation [12-15]), Advanced Oxidation Processes (AOPs) have proven effective for degrading organic compounds like BPA. AOPs are considered ecologically friendly methods for sewage treatment [16]. Therefore, exploring their chemical nature and oxidation mechanisms, and finding effective treatment solutions is extremely important. It also provides new practical scenarios and a theoretical basis for solving environmental problems, improving resource utilization efficiency, promoting industry development, and fostering scientific research and technological innovation. It offers efficient and environmentally friendly wastewater treatment and resource recycling solutions for the mining industry.

3. Advantages of Stacked MFCs in Pollutant Treatment and Power Output

The main principle of stacked MFC systems is still based on dual-chamber or triple-chamber MFCs. The primary configurations of current stacked MFCs mainly include flat, alternating

ISSN: 2710-0170

stacking of anodes and cathodes, and multiple cathodes and anodes arranged around a desalination chamber. In these models, the basic unit's anode and cathode are connected by metal wires, and then the system's circuit is formed by connecting the basic units in parallel or series. Parallel and series configurations enhance the system's output current or voltage, increasing the system's output power density. After improving the system's power output, the application of MFC systems has taken a solid step towards practicality. Gurung et al. discussed the improvement of power output in stacked microbial fuel cells (MFCs). By connecting multiple MFC units in series or parallel, they increased voltage and current production. Experimental results showed that in series connection, the total voltage of the stacked MFC equaled the sum of the voltages of individual MFCs; whereas in parallel connection, the current level increased approximately threefold. However, series connection may lead to the phenomenon of voltage reversal, thus affecting the performance of the entire stack [17]. Multi-anode shared cathode is also a hotspot in MFC research. Shared cathodes have higher power density and lower internal resistance than ordinary MFCs [18]. Opoku et al. studied the performance of a novel multi-anode shared cathode MFC (MASC-MFC) compared to a standard single anode/cathode MFC (SAC-MFC) and simultaneously treated different types of real wastewater (sewage, slaughterhouse, and hospital) in the same MFC unit. The power density and current density of the MASC-MFC were 1.7 times and 1.6 times higher than those of the standard SAC-MFC, respectively, with internal resistance reduced by 2.2 times. The maximum COD removal efficiency for synthetic wastewater reached 62.7%. Adding multiple real wastewaters to the MASC-MFC reduced the maximum power density by 3.5 times and increased internal resistance by 2.7 times. Despite the complex composition of the wastewater, stable current generation was achieved within 300 hours. Regardless of the type of actual wastewater, the MASC-MFC independently achieved coulombic efficiencies exceeding 40% and around 30% in all anode chambers [19]. Others have optimized the single-chamber microbial fuel cell (MFC) architecture by increasing the number of cathode electrodes. Increasing from 4 air cathodes (total cathode surface area 160 cm^2) to 6 air cathodes (total cathode surface area 240 cm^2), the cell's maximum current and maximum power output increased by approximately 72% and 129%, respectively. Furthermore, by increasing the cathode surface area, the unit's internal resistance decreased by approximately 19%. The organic removal of the substrate was not affected by the addition of new electrodes (Chemical Oxygen Demand (COD) removal >89% in all cases studied). Power also increased with the addition of electrodes [20]. Multi-anode/cathode configurations as extensions of standard MFCs have also received significant attention. Researchers studied the feasibility of applying microbial fuel cell (MFC) technology to ethanolamine wastewater treatment. Using a dual anode/cathode MFC stack system with actual ethanolamine wastewater enabled energy recovery and ethanolamine removal. Experimental results showed that by adjusting the ratio of synthetic medium to actual wastewater in the MFC unit, better current output could be obtained. Furthermore, by connecting multiple MFC units in series, continuous wastewater treatment could be achieved. The study also explored the performance of the stacked MFC system at different flow rates and evaluated the removal efficiency of COD and ammonia [21].

4. Applications of Microbial Fuel Cells

Microbial fuel cells (MFCs) are receiving increasing attention in the field of wastewater treatment because they can remove organic pollutants while also producing bioenergy and releasing hydrogen. Photosynthetic biofilm MFCs, constructed wetland MFCs, and ceramic membrane MFCs for deionizing chemical pollutants in wastewater are developing into effective methods. Wastewater deionization in microbial fuel cells involves electro-microbial power generation, where biomass and bioenergy (electricity) are produced as by-products in this process [24-28]. This treatment method offers a simple and environmentally friendly water

ISSN: 2710-0170

deionization process, requiring less energy consumption during operation. Therefore, microbial fuel cells are proven to be a promising technology for effectively removing pollutants from wastewater. Microbial desalination using fuel cells is proven to be a promising technology for wastewater treatment and desalination. By utilizing organic pollutants in wastewater as a substrate and providing essential biogas and bioelectricity with the aid of electricigens, pollution-free and desalinated water can be obtained from wastewater. Zhou Yuhong et al. developed a novel membraneless microbial fuel cell (MLMFC), using baffles instead of ion exchange membranes (IEM) for ammonium-containing wastewater treatment and power generation. By installing an ideal nitrification unit between the anode and cathode chambers, the new ML-MFC achieved organic degradation and denitrification without additional recirculation. Combined with analysis of microbial communities, electroactive bacteria (EAB) such as Desulfovibrio, Comamonas, and Thiobacillus were enriched in the biofilm. Considering the superior effluent quality and promising energy potential, the novel ML-MFC has broad application prospects in efficient and sustainable wastewater treatment [29]. Researchers studied the feasibility of using microbial fuel cells (MFCs) to treat coconut industry wastewater and produce bioenergy. Through experiments and research, the authors explored the impact of different operating conditions on the effectiveness of MFC treatment of coconut water and bioenergy production [30].

5. Conclusion

In summary, facing the environmental pressure and energy crisis brought about by fossil fuel consumption, developing sustainable wastewater treatment and energy recovery technologies has become a global consensus. Microbial fuel cell (MFC) technology, as an emerging platform that combines pollutant degradation with chemical energy conversion for electricity production, offers a highly potential solution for simultaneously addressing energy and environmental problems. This review systematically discusses the unique advantages of MFC technology in treating refractory organic pollutants (represented by BPA) and recovering energy. Compared with traditional treatment processes, MFC technology is environmentally friendly, requires no large external energy input, allows for the resource recovery of electrical energy, and has a low risk of secondary pollution, highly aligning with the national strategic direction of promoting renewable energy development and prioritizing its development and utilization. Addressing the composite pollution of BPA and heavy metals in complex water bodies like mine water, developing novel MFC configurations (such as photocatalytically assisted anodes, stacked MFCs, multi-anode shared cathode MFCs, etc.) is key to enhancing treatment efficiency and power output. Literature indicates that through electrode material modification, reactor structure optimization (e.g., series/parallel stacking), and operational condition regulation, the system's pollutant removal rate, coulombic efficiency, output voltage, and power density can be significantly enhanced, thereby promoting the advancement of MFC technology from laboratory scale towards practical application. Although application research on MFC technology in the field of wastewater treatment has made significant progress, its large-scale engineering application still faces challenges in cost, long-term operational stability, and output power. In conclusion, MFC technology, as a green and sustainable cutting-edge technology, shows broad application prospects in mining area environmental remediation, refractory wastewater treatment, and bioenergy recovery. Through continuous technological innovation and interdisciplinary integration, MFCs are expected to make important contributions to solving energy, resource, and environmental problems.

ISSN: 2710-0170

Acknowledgements

This work was financially supported by Higher Education Scientific Research Project of Hebei Education Department (JCZX2025010 and QN2025431), Key R & D project in Hebei Province (22323601D), Tangshan Basic Research Science and Technology Project (24130209C and 23130212E).

References

[1] ABO R, KUMMER N A, MERKEL B J. Optimized photodegradation of Bisphenol A in water using ZnO, TiO_2 and SnO_2 photocatalysts under UV radiation as a decontamination procedure[J]. Drinking Water Engineering and Science, 2016, 9(2): 27-35.

[2] Fu Yuanhang, Liu Andi, Huang Weibin, etc Electrocatalytic oxidation of bisphenol A on porous Ti/SnO2-Sb Ni electrode loaded with multi walled carbon nanotubes [J]. Environmental Science, 2022,43 (05): 2640-2649. DOI: 10.13227/j.hjkx.202109005

[3] Li Jiang, Wang Yan, Zhang Xiufang, etc Co3O4/BiVO4 composite anode activated persulfate enhanced photocatalytic degradation of bisphenol A [J]. Environmental Science, 2018, 39 (08): 3713-3718. DOI: 10.13227/j.hjkx.201711036XIAO C, WANG L, ZHOU Q, et al. Hazards of bisphenol a (BPA) exposure: A systematic review of plant toxicology studies[J]. Journal of Hazardous Materials, 2019, 384: 121488.

[4] JATOI A S, HASHMI Z, MAZARI S A, et al. A comprehensive review of microbial desalination cells for present and future challenges[J]. Desalination, 2022, 535: 115808.

[5] WANG Y, LI J, MA T, et al. Genesis of geogenic contaminated groundwater: As, F and I[J]. Critical Reviews in Environmental Science and Technology, 2021, 51(24): 2895-2933.

[6] XU F, LI P, DU Q, et al. Seasonal hydrochemical characteristics, geochemical evolution, and pollution sources of Lake Sha in an arid and semiarid region of northwest China[J].Exposure and Health, 2023, 15(1): 231-244.

[7] ZHANG J, CHEN L, HOU X, et al. Effects of multi-factors on the spatiotemporal variations of deep confined groundwater in coal mining regions, North China[J]. Science of the Total Environment, 2022, 823: 153741.

[8] ZHANG C, BAI Q, HAN P. A review of water rock interaction in underground coal mining: Problems and analysis[J]. Bulletin of Engineering Geology and the Environment, 2023, 82(5): 157.

[9] Ge Guangrong, Wu Yiping, Zhang Quan Research on Moderate Desalination Technology of High Mineralization Mine Water Nanofiltration Membrane [J]. Coal Science and Technology, 2021, 49 (3): 208-21

[10] ALI H E B, NECULITA C M, MOLSON J W, MAQSOUD A, ZAGURY G Z. Efficiency of batch biochemical reactors for mine drainage treatment at low temperature and high salinity[J]. Applied Geochemistry, 2019, 103: 40-49.

[11] BAI X, ZHANG X, HUA Z, et al. Uniformly distributed anatase TiO2 nanoparticles on graphene: Synthesis, characterization, and photocatalytic application[J]. Journal of alloys and compounds, 2014, 599: 10-18.

[12] BECHAMBI O, CHALBI M, NAJJAR W, et al. Photocatalytic activity of ZnO doped with Ag on the degradation of endocrine disrupting under UV irradiation and the investigation of its antibacterial activity[J]. Applied Surface Science, 2015, 347: 414-420.

[13] Wang Hao, Feng Chenglian, Guo Guanghui, etc Ecological risk assessment of bisphenol A (BPA) in freshwater bodies in China [J]. Environmental Science, 2013, 34 (06): 2319-2328. DOI: 10.13227/j.hjkx.2013.06.018

[14] Xiang Guoliang, Yu Zebin, Chen Ying, etc Study on simulated solar photocatalytic degradation of bisphenol A using iron doped TiO2 nanotube arrays [J]. Environmental Science, 2015, 36 (02): 568-575. DOI: 10.13227/j.hjkx. 2015.02.026

[15] SU Y, YANG Y, JIANG W, et al. A novel strategy of peracetic acid activation by dielectric barrier discharge plasma for bisphenol a degradation: Feasibility, mechanism and active species dominant to degradation pathway[J]. Chemical Engineering Journal, 2023, 476: 146469

[16] XU J, SHENG G P, LUO H W, et al. Fouling of proton exchange membrane (PEM) deteriorates the performance of microbial fuel cell[J]. Water research, 2012, 46(6): 1817-1824.

[17] YANG S, JIA B, LIU H. Effects of the Pt loading side and cathode-biofilm on the performance of a membrane-less and single-chamber microbial fuel cell[J]. Bioresource Technology, 2009, 100(3): 1197-1202.

[18] OPOKU P A, JINGYU H, YI L, et al. Scaled-up multi-anode shared cathode microbial fuel cell for simultaneous treatment of multiple real wastewaters and power generation[J]. Chemosphere, 2022, 299: 134401.

[19] KAMPERIDIS T, TREMOULI A, LYBERATOS G. Architecture Optimization of a Single-Chamber Air-Cathode MFC by Increasing the Number of Cathode Electrodes[J]. Sustainability, 2023, 15(17): 13107.

[20] ZAHRAN M. Iron-and carbon-based nanocomposites as anode modifiers in microbial fuel cells for wastewater treatment and power generation applications[J]. Journal of Water Process Engineering, 2024, 64: 105679.

[21] AN B M, HEO Y, MAITLO H A, et al. Scaled-up dual anode/cathode microbial fuel cell stack for actual ethanolamine wastewater treatment[J]. Bioresource technology, 2016, 210: 68-73.

[22] Yan Weifu, Xiao Yong, Wang Shuhua, etc Microbial fuel cell treatment and microbial community of oxytetracycline [J]. Environmental Science, 2018, 39 (03): 1379-1385. DOI: 10. 13227 /j .hjkx.201708189

[23] LIU Y, ZHU G, GAO J, et al. Enhanced photocatalytic activity of Bi4Ti3O12 nanosheets by Fe3+-doping and the addition of Au nanoparticles: photodegradation of phenol and bisphenol A[J]. Applied Catalysis B: Environmental, 2017, 200: 72-82.

[24] Qu Youpeng, Lv Jiangwei, Dong Yue, etc Mechanism of electrocatalytic bioelectrochemical coupling system for treating penicillin wastewater [J]. Environmental Science, 2021, 42 (05): 2378-2384. DOI: 10.13227/j.hjkx.202007300

[25] Zubo, Malan, Liu Bo, etc The effect of organic matter on the denitrification and electricity production performance of anaerobic ammonia oxidation microbial fuel cells [J]. Environmental Science, 2018, 39 (08): 3937-3945. DOI: 10.13227/j.hjkx.201711104

[26] Li Jiang, Wang Yan, Zhang Xiufang, etc Co3O4/BiVO4 composite anode activated persulfate enhanced photocatalytic degradation of bisphenol A [J]. Environmental Science, 2018, 39 (08): 3713-3718. DOI: 10.13227/j.hjkx.201711036

[27] LI Z L, CHENG R, CHEN F, et al. Selective stress of antibiotics on microbial denitrification: inhibitory effects, dynamics of microbial community structure and function[J]. Journal of Hazardous Materials, 2021, 405: 124366.

[28] Zhou Y, Zhao S, Yin L, et al. Development of a novel membrane-less microbial fuel cell (ML-MFC) with a Sandwiched Nitrifying chamber for efficient wastewater treatment[J]. Electroanalysis, 2018, 30(9): 2145-2152.

[29] Sreedharan S, Pawels R. Feasibility study on treatment of coconut industry wastewater and bioenergy production using microbial fuel cell (MFC)[J]. International Journal of Environmental Science and Technology, 2022, 19(6): 5333-5342.