XVI International Mineral Processing
and Recycling Conference
28-30 May 2025, Belgrade, Serbia

DOI: 10.5937/IMPRC25256S Original research article

ELECTROCHEMICAL OXIDATION OF BISPHENOL S WITH SnO_2-MWCNT ELECTRODES

Marija Simić[#], 0000-0001-9518-7709,
Marija Kovačević, 0000-0001-8858-6728,
Katarina Stojanović, 0009-0003-3467-9875,
Branislava Savić Rosić, 0000-0002-4632-7960,
Dragana Vasić Anićijević, 0000-0003-0566-3244,
Tanja Brdarić, 0000-0003-2547-7123,
Danka Aćimović, 0000-0001-7506-9684,
"Vinča" Institute of Nuclear Sciences-National Institute of the Republic of Serbia, Department of Physical Chemistry, Belgrade, Serbia

ABSTRACT – Bisphenol S (BPS) is a synthetic compound frequently used as an alternative to Bisphenol A (BPA) in the manufacture of various plastics and resins. Its widespread use has led to its detection in environmental samples, raising concerns about its potential endocrine-disrupting effects and toxicity. Recent research shows that BPS can leach from consumer products and accumulate in aquatic ecosystems, posing risks to both aquatic organisms and human health. Electrochemical oxidation of BPS has emerged as a promising approach for its degradation.

This study examines the electrochemical oxidation of Bisphenol S utilizing SnO_2-MWCNT (multi-walled carbon nanotubes) electrodes in a galvanostatic regime at different current densities (10, 15 and 20 mA cm^{-2}). The main objective of this study was to compare the removal efficiency and energy consumption during the degradation of BPS on various current densities. Experimental results indicated that an increase in current density corresponds to a rise in both removal efficiency and energy consumption. However, this observation highlights the necessity for careful optimization to balance efficiency and energy consumption in real-world applications.

Keywords: Bisphenol s, Electrochemical oxidation, SnO_2-MWCNT electrodes.

INTRODUCTION

Bisphenol S (BPS) was introduced as an alternative to bisphenol A (BPA) due to growing concerns over BPA's potential health and environmental risks. It has since become widely utilized in the production of polycarbonate plastics and epoxy resins, which are commonly found in various consumer products, including food packaging, thermal paper, and electronic components. Bisphenol S (BPS) is structurally characterized by two hydroxyphenyl groups connected by a sulfonyl group, making it closely related to bisphenol A (BPA). Due to this structural similarity, concerns have been raised about its safety and the possibility of similar adverse effects. Notably, BPS exhibits

[#] corresponding author: marija.simic@vin.bg.ac.rs

greater resistance to heat and sunlight than BPA, making it a more durable alternative in industrial applications [1]. However, despite its widespread use, research on its safety remains limited. Preliminary studies suggest that BPS may pose equal or even greater risks than BPA in certain biological and environmental contexts. Several studies have reported its potential adverse effects on biological systems. These studies have highlighted concerns regarding its ability to disrupt the endocrine system, leading to hormonal imbalances that may affect various physiological functions. Additionally, BPS has been linked to cytotoxicity, indicating its potential to damage or impair cellular function. Some findings suggest that it may also exhibit mutagenic properties, raising concerns about its ability to induce genetic mutations that could contribute to long-term health risks. Furthermore, research has associated BPS exposure with an increased risk of obesity, potentially due to its impact on metabolic regulation. Notably, studies have also suggested that BPS may cause reproductive and developmental toxicity, posing risks to fertility, fetal development, and overall reproductive health. Despite these findings, further in-depth research is necessary to fully understand the extent of BPS toxicity and its implications for human and environmental health [2]. As the primary substitute for bisphenol A (BPA), bisphenol S (BPS) has become widely used in various industrial and consumer applications. Its production and utilization have significantly increased over the years, with the European Chemicals Agency (ECHA) reporting that the annual manufactured or imported volume of BPS in the European Economic Area ranged between 1,000 and 10,000 tons as of 2015. On a global scale, BPS has been detected extensively in aquatic environments, including surface water, riverine systems, and marine sediments, as well as in wastewater sludge. Its widespread presence in different environmental matrices highlights its persistence and potential for bioaccumulation [1]. The widespread presence of BPS raises concerns about its long-term effects on the environment and the potential risks it may pose to both wildlife and humans with continued exposure.

In addition to conventional methods for pollutant removal (coagulation, adsorption, membrane filtration, biological treatments, etc.), research is also focused on developing electrochemical advanced oxidation processes, which offer lower environmental risks and economic feasibility. Among these, electrochemical oxidation stands out as it utilizes electricity instead of additional chemicals to oxidize organic pollutants, often degrading them into carbon dioxide and water, depending on factors such as electrode material, applied current, and electrolysis duration [3, 4].

The aim of this study is to investigate the effect of current on the efficiency of bisphenol S removal from polluted wastewater, as well as its energy consumption, using electrochemical oxidation with a SnO_2-MWCNT electrode. A comprehensive comparison of BPS removal efficiency and energy consumption at various current densities is essential for optimizing the electrochemical oxidation process. By analyzing how different current densities influence both the effectiveness of BPS removal and the energy required, it is possible to identify the most efficient operating conditions, which can lead to more sustainable and cost-effective wastewater treatment methods.

MATERIALS AND METHODS

To evaluate the effect of current density on the degradation efficiency of bisphenol S, experiments were carried out in a two-electrode electrolytic cell. The setup included SnO_2-MWCNT electrodes as the working electrodes and stainless steel as the counter electrode. Electrolytic degradation was conducted at varying current densities of 10, 15, and 20 mA cm^{-2} under room temperature conditions. A Gamry Instruments Interface 1000 Potentiostat/Galvanostat (Gamry Instruments, USA) was used to regulate the electrochemical oxidation. It was performed on a 30 mg/L solution of bisphenol S in 0.01 M sodium sulfate at pH 4. Electrolyte samples were collected every hour over a 5-hour electrolysis period. To determine the concentration of BPS in the aliquots, liquid-liquid extractions were conducted using dichlor methane [4]. The extracts were then concentrated and analyzed by GC-MS [3].

The concentration of bisphenol S in the electrolyte was measured using a calibration curve, and the removal efficiency (%) was subsequently calculated using the following equation:

$$Efficiency\ removal = \frac{C_0 - C_t}{C_0} \tag{1}$$

where c_o (mol dm^{-3}) is initial concentration BPS, c_t (mol dm^{-3}) represents the concentration of BPS in the aliquot taken at a specific time (t) of electrochemical degradation.

Overall, to analyze energy consumption at different current densities, the energy consumption per order (EE_0) in kWh/m^3 was calculated using Equation 2.

$$EE_0 = 1000\frac{\mathrm{Pt}}{Vlog\frac{C_0}{C_t}} = 1000\frac{\mathrm{UIt}}{Vlog\frac{C_0}{C_t}} \tag{2}$$

where t is time of electrolysis (h), U (V) is applied potential in electrochemical system, and I (A) is applied current in electrochemical system [5].

RESULTS AND DISCUSSION

The electrolytic oxidation of 30 mg L^{-1} BPS was carried out at varying current densities of 10.0, 15.0, and 20.0 mA cm^{-2}. As shown in Figure 1, the removal efficiency of BPS increases as the current density rises, which aligns with findings from previous studies in the literature [6]. Notably, the most significant reduction in BPS concentration occurs during the first hour of electrolysis, with the removal efficiency showing a clear positive correlation with current density. During this period, the BPS concentration decreases by approximately 30% relative to the initial concentration at current densities of 15.0 and 20.0 mA cm^{-2}, indicating the enhanced effectiveness of the electrolytic oxidation process at higher current densities. This trend highlights the crucial role of current density in optimizing the efficiency of BPS removal from the electrolyte.

A significant difference in BPS removal is observed between current densities of 10 mA cm^{-2} and 20 mA cm^{-2}, resulting in efficiencies of 73.4% and 89.2%, respectively. However, the difference in efficiency removal between 20.0 mA cm^{-2} and 15.0 mA cm^{-2} is minimal, less than 4%, indicating that further increases in current density do not significantly affect the degradation efficiency.

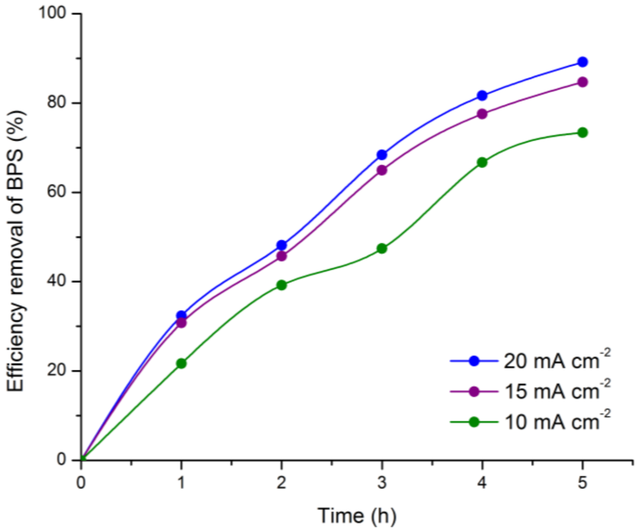

Figure 1 Efficiency removal of 30 mg L^{-1} 1 BPS at different current densities during anodic oxidation

The electric energy per order (EE_0), which is present an effective parameter for estimating energy consumption, is 9.4 kWh·m^{-3} on current density 10 mA cm^{-2}, 10.0 kWh·m^{-3} on 15.0 mA cm^{-2}, and 12.7 kWh·m^{-3} on 20.0 mA cm^{-2}. As it is depicted in Figure 2, calculated EE_0 indicates that an increase in current density leads to higher energy consumption, particularly at a current density of 20.0 mA cm^{-2}.

Based on these results and previous literature observations [7], it can be suggested that higher current densities likely accelerate parasitic reactions, such as O_2 generation, leading to increased energy consumption.

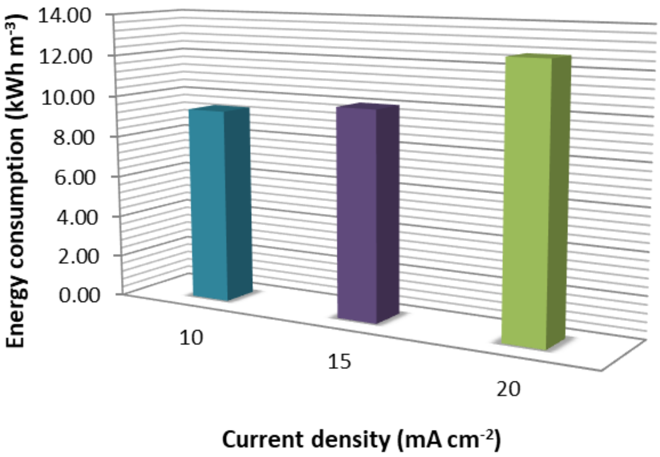

Figure 2 Energy consumption during anodic oxidation of BPS at different current densities

Considering that the efficiency removal of BPS at current densities of 15.0 and 20.0 mA cm^{-2} is similar, while energy consumption differs, electrochemical oxidation at a current density of 15.0 mA cm^{-2} should be selected for the most efficient operating conditions.

CONCLUSION

In conclusion, the electrolytic oxidation of BPS demonstrated that increasing current density improves the efficiency removal, with a notable reduction in BPS concentration occurring within the first hour of electrolysis. The degradation efficiency significantly differs between current densities of 10.0 and 20.0 mA cm^{-2}, with a minimal difference between 15.0 and 20.0 mA cm^{-2}. While higher current densities enhance BPS removal, they also result in increased energy consumption, particularly at 20.0 mA cm^{-2}. Therefore, a current density of 15.0 mA cm^{-2} is optimal, as it provides a more favorable balance between effective removal of bisphenol S and reduced energy consumption, making it the optimal choice for achieving efficient and cost-effective operating conditions in the process.

ACKNOWLEDGEMENT

This work was supported by the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia [grant number 451-03-136/2025-03/200017].

REFERENCES

1. Oh, J., Choi, J.W., Ahn, Y.A., Kim, S. (2018) Pharmacokinetics of bisphenol S in humans after single oral administration. Environment International 112, 127–133.
2. Wu, L.H., Zhang, X.M., Wang, F., Gao, C.J., Chen, D., Palumbo, J.R., Guo, Y., Zeng, E.Y. (2018) Occurrence of bisphenol S in the environment and implications for human exposure: A short review. Science of the Total Environment 615, 87–98.
3. Simić, M.D, Brdarić, T.P., Savić Rosić, B.G., Švorc, Ľ., Relić, D.J., Aćimović, D.D. (2024) Degradation of bisphenol A via the electro–Fenton process using nanostructured carbon-metal oxide anodes: Intermediates and reaction mechanisms study. Journal of Environmental Chemical Engineering, 12 (5), 113369.
4. Simić, M.D., Savić, B.G., Ognjanović, M.R., Stanković, D.M., Relić, D.J., Aćimović, D.D., Brdarić, T.P. (2023) Degradation of bisphenol A on SnO_2-MWCNT electrode using electrochemical oxidation. Journal of Water Process Engineering 51, 103416.
5. Bolton, J.R., Bircher, K.G., Tumas, W., Tolman, C.A. (2001) Figures-of-merit for the technical development and application of advanced oxidation technologies for both electric- and solar-driven systems. Pure and Applied Chemistry 73 (4), 627–637.
6. Wu, W., Huang, Z., Hu, Z.-T., He, C., Lim, T. (2017) High performance duplex-structured SnO_2-Sb-CNT composite anode for bisphenol A removal. Separation and Purification Technology 179, 25–35.
7. Cai, J., Zhou, M., Pan, Y., Lu, X. (2020) Degradation of 2,4-dichlorophenoxyacetic acid by anodic oxidation and electro-Fenton using BDD anode: Influencing factors and mechanism. Separation and Purification Technology 230, 115867.