

Abstract

FROM WASTE TO RESOURCE: A SUSTAINABLE APPROACH TO LEACHING OF SULFIDIC TAILINGS

DOI: 10.5937/EcoTER26002B

Grozdana Bogdanović^{1,a*}

¹ University of Belgrade, Technical Faculty in Bor, Vojske Jugoslavije 12, 19210 Bor, SERBIA

^a <https://orcid.org/0000-0002-1013-4075>

Abstract

The mining industry plays a key role in a country's development, contributing significantly to both economic and technological progress. However, mining activities often cause considerable environmental impacts. Sulfide-rich tailings are commonly associated with acid mine drainage (AMD), heavy metal mobilization, and long-term environmental contamination. These tailings are residues from the mineral concentration stage, and are therefore predominantly composed of gangue minerals, such as quartz (SiO₂), carbonates (CaCO₃), various oxides (Al₂O₃, MgO, Fe₂O₃, Fe₃O₄), as well as pyrite (FeS₂). Additionally, these tailings contain sulfide minerals such as chalcopyrite (CuFeS₂), sphalerite (ZnS), galena (PbS), and pyrrhotite (Fe_{1-x}S), which remain after the extraction of economically valuable metals from ores. Meanwhile, advances in resource recovery technologies have shown that many historical and active tailings deposits still contain significant concentrations of critical and valuable metals, including cobalt, nickel, zinc, copper, rare earth elements, and precious metals. In recent years, rising global demand for critical raw materials, driven by the energy transition, electrification, and low-carbon technologies, has intensified interest in tailings reprocessing as a secondary resource strategy. Sustainable leaching technologies have emerged as promising methods for recovering residual metals from sulfidic tailings while simultaneously reducing the environmental liabilities associated with long-term tailings storage. Traditional acidic leaching systems based on sulfuric acid remain widely used due to their high extraction efficiency; however, these processes often involve substantial chemical consumption and generate secondary waste streams. Consequently, current research increasingly focuses on sustainable alternatives such as bioleaching, glycine leaching, ionic liquids, deep eutectic solvents (DES), chloride systems, and oxidative alkaline leaching. Among these approaches, bioleaching has attracted considerable attention because of its low energy requirements and reduced environmental impact. This review examines recent advances in sustainable leaching technologies for processing sulfide tailings and highlights some of the challenges and opportunities for future research. It focuses on their role in circular economy strategies, the recovery of critical metals, and the sustainable management of mining waste

Keywords: sulfidic tailings, metal recovery, leaching, mining waste valorization, circular economy.

* gbogdanovic@tfbor.bg.ac.rs

ACKNOWLEDGEMENT

The author is grateful to the Ministry of Science, Technological Development and Innovation of the Republic of Serbia for financial support according to the contract with registration No. 451-03-34/2026-03/200131.

REFERENCES

- [1] Zou, K., Zhang, Y., Shen, L., *et al.* Chem. Eng. J. 2025, 503, 158198.
- [2] Nakhaei, F., Corchado-Albelo, J., Alagha, L., *et al.* Sep. Purif. Technol. 2025, 354 (4), 128973.
- [3] Marilović, D., Bogdanović, G., Stevanović, Z., *et al.* Min. Metall. Explor. 2026, 43 (1), 657–672.
- [4] Petrović, S., Bogdanović, G., Antonijević, M. Trans. Nonferrous Met. Soc. China. 2018, 28 (7), 1444–1455.
- [5] Stanković, V., Milošević, V., Miličević, D., *et al.* Chem. Ind. Chem. Eng. Q. 2018, 24 (4), 333–344.
- [6] Petrović, S.J., Bogdanović, G.D., Antonijević, M.M., *et al.* Min. Metall. Explor. 2026, 43(2), 1935–1949.
- [7] Petrović, S.J., Bogdanović, G.D., Antonijević, M.M., *et al.* Metals. 2023, 13 (11) 1818.
- [8] Kinnunen, P., Karhu, M., Yli-Rantala, E., *et al.* Clean Eng. Technol. 2022, (8), 100499.
- [9] Behnajady, B., Najafi, M., Saeid Karimi, S.J. Taiwan Inst. Chem. Eng. 2025, (172), 106118.
- [10] Kursunoglu, S. J. Sustain. Metall. 2025, 11, 2023–2050.
- [11] Araujo, F.S.M., Taborda-Llano, I., Nunes, E.B., *et al.* Geosciences. 2022, 12, 319.
- [12] Schueler, T.A., de Aguiar, P.F., Vera, Y.M., *et al.* J. Sustain. Metall. 2021, 7, 1523–1536.
- [13] Maltrana, V., Morales, J. Metals. 2023, 13, 1862.
- [14] Wang, D., Liu, Q. Hydrometallurgy. 2026, 243, 106723.
- [15] Crane, R.A., Mohammad, A., Jin, F., *et al.* Hydrometallurgy. 2025, 236, 106506.
- [16] Jamett, I., Carrasco, P., Olmos, M., Hernández, P. Minerals. 2023, 13, 22.
- [17] Zante, G., Yu Boltoeva, M. Sustain. Chem. 2020, 1, 238–255.
- [18] Tezyapar Kara, I., Kremser, K., Wagland, S.T., *et al.* Environ. Chem. Lett. 2023, 21, 3329–3350.
- [19] Watling, H.R., Watkin E.L.J., Ralph, D.E. Environ. Technol. 2010, 31 (8–9), 915–933.
- [20] Antonijević, M.M., Dimitrijević, M., Stevanović, Z.O., *et al.* Hazard. Mater. 2008, 158 (1), 23–34.
- [21] Stevanović, Z.O., Antonijević, M.M., Bogdanović, G.D., *et al.* Chem. Ecol. 2011, 27 (5), 401–414.