

Integrated Approaches to Eco-Friendly Processes for Persistent Pollutants Contamination

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All life on Earth is fully affected by the environment’s health and sustainability [1]. In recent decades, there has been an increasing emphasis on promoting and enhancing human well-being through contexts that relate to the pillars of sustainable development, improving education, health and environmental quality [2]. Unfortunately, although the industrial revolution brought economic growth and therefore a higher standard of living, there have been numerous situations in which the quality of the environment has suffered [3]. In addition to industrialization damaging the quality of the environment, harmful agricultural processes have proven to be an obstacle to environmental and human well-being [4–6]. Therefore, the ultimate elimination of persistent pollutants with detrimental impacts on the environment, aquatic organisms and human health is vital in science and technology, being the focus of researchers through approaches emphasizing environmentally friendly processes [7–9].

Processes based on the principle of the bioremediation of environmental contaminants have generally demonstrated their success at the laboratory scale [10,11], while their up-scaling often remains a real issue in terms of practical applicability [12,13]. Furthermore, bioremediation processes’ impacts and risks on the environment and human health or the design costs of carrying out the technology transfer in treatment plants requires research and consideration [14]. For example, by integrating life cycle assessment and life cycle cost methodologies for wastewater treatment processes in an early design phase, or a pre-design phase, we can identify justified environmental and economic design strategies linked to sustainable perspectives, not only from an industry point of view but also from a consumer point of view [15–17]. In this context, the Special Issue on “Integrated Approaches to Eco-Friendly Processes for Persistent Pollutants Contamination” drew attention to the latest work of the scientific community, the cutting-edge recent advances in bioremediation technology for persistent pollutant removal. This Special Issue is currently available online at https://www.mdpi.com/journal/processes/special_issues/241177AG8M (accessed 26 November 2024).

The multi-disciplinary nature of the scientific contributions is revealed in this Special Issue, which we hope will represent a pathway towards a smoother transition from the linear to the circular economy, as each detailed approach is based on the application of sustainable processes for environmental remediation and contaminant removal. This Special Issue on “Integrated Approaches to Eco-Friendly Processes for Persistent Pollutants Contamination” comprises one review and five research articles that have been accepted and published.

In their review, Filote et al. (Contribution 1) analyzed the potential for implementing continuous metal removal processes in reactors using microorganisms as sorbents, previously identified in different studies in the field. The authors considered the possibility of the regeneration of microbial sorbents via desorption for multiple applications designed



Citation: Hlihor, R.-M.; Simion, I.M.; Roșca, M. Integrated Approaches to Eco-Friendly Processes for Persistent Pollutants Contamination. *Processes* **2024**, *12*, 2812. <https://doi.org/10.3390/pr12122812>

Received: 28 November 2024

Accepted: 5 December 2024

Published: 9 December 2024



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for the remediation of heavy metal contaminated effluents, and furthermore, they carried out a comprehensive evaluation of the impacts of microbial processes by applying the life cycle assessment (LCA) methodology. Based on the summarized scientific information, data quality and data availability for conducting an LCA study, the authors concluded that more studies on optimization parameters, performance analysis in multiple sorption–desorption cycles for metal removal, and sustainability analysis (in terms of energy and fuel consumption during process development) applied to continuous and pilot-scale systems are needed to develop a sustainable microbial-based process for heavy metal removal. An approach focusing on real effluent analysis is also needed for future research work in continuous systems.

The biodegradation and photocatalysis of Rhodamine B (RhB), a synthetic dye used in textiles and food, were compared in the study conducted by Chadelaud et al. (Contribution 2). For biodegradation tests, the yeast *Saccharomyces cerevisiae* was used, while TiO₂ doped with 5% cerium under UV light was used for photocatalysis. The study's results showed that *S. cerevisiae* cannot biodegrade RhB; rather, it can only bind to its surface through biosorption, achieving an uptake capacity of 4.2 mg g^{−1} and a removal efficiency of 13% after 150 min. In contrast, photocatalytic treatment of 5 mg L^{−1} RhB resulted in a 55% removal of color and an 8.6% reduction in total organic carbon. Notably, the biodegradability of the photocatalyzed solution increased, as evidenced by an increase in the BOD₅/COD ratio from 0.10 to 0.42. Through phytotoxicity and aquatic toxicity studies, the authors highlighted the importance of carefully assessing the photocatalytic by-products of RhB, especially when considering larger-scale environmental applications. At concentrations up to 5 mg L^{−1}, RhB does not exhibit any phytotoxicity on watercress seeds. However, at concentrations of 10 mg L^{−1} and 25 mg L^{−1}, it showed moderate toxicity, resulting in a germination index of 50% to 80% for seeds. At concentrations of 50 mg L^{−1} and 100 mg L^{−1}, RhB is highly toxic, leading to a germination index of less than 45%. The photocatalyzed solution exhibited greater toxicity than the untreated RhB at 5 mg L^{−1}, likely due to the formation of toxic degradation by-products. Despite the increased phytotoxicity, the photocatalytic by-products had no impact on the mobility of *Daphnia magna*, suggesting selective toxicity profiles for different organisms. The authors point out the novelty of the study involving scrutinizing both the effectiveness of two treatment processes and the ecotoxicity of by-products.

The study conducted by Kirilova et al. (Contribution 3) examined the alterations in the structure, composition, and enzymological profile of the activated sludge microbiome during its adaptation to leachate over a 21-day simulation period in a sequencing batch reactor (SBR). In experiments with undiluted leachate, the chemical oxygen demand (COD) increased by 2.6 times. Additionally, phosphate levels increased by 218 times, nitrite levels increased by 49 times, and ammonium ion concentrations increased to 573 mg/L, indicating a significant inhibition of the nitrification process. Furthermore, the extremely low solid volume index (SVI) of 4.6 mL/g suggested an almost complete breakdown of the activated sludge structure. The analysis of the community involved in landfill treatment showed that at the end of the process, in the homogeneous phase, aerobic heterotrophs constituted 71% of the total microorganisms on day 21, while 5% were identified as *Pseudomonas* species, 11% as *Acinetobacter* species, and another 5% as denitrifying bacteria. Compared to the initial composition of activated sludge, the number of aerobic heterotrophs was nearly seven times higher, *Pseudomonas* increased by 58 times, *Acinetobacter* increased by 299 times, and denitrifying bacteria increased by 17 times. These changes highlight the ability of the activated sludge microbiome to adapt to undiluted leachate. However, the significant inhibition of nitrification and structural degradation indicates that there are still challenges that must be addressed for sustainable landfill leachate treatment.

The aim of Bogdanova et al.'s (Contribution 4) study was to make a comparative assessment of the Ravda wastewater treatment plant (WWTP) activity in the summer and winter seasons and its efficiency, considering the years of the COVID-19 pandemic (2018–2022 inclusive), when a significantly higher water consumption per person was

observed. In their study, the authors analyzed the influent and effluent BOD₅ and COD and the efficiency of nitrogen and phosphorus removal from the WWTP. In line with the results, the authors concluded that despite the resorts' efforts to use reusable utensils and containers, as well as other investments aimed at reducing resource use (water, electricity), the management cycle is still linear, with small exceptions for hotel chains built after the COVID-19 pandemic. One recommendation for maintaining a high-quality standard of treated water quality from the Ravda WWTP operation, even during more populated periods, is the use of biotechnology (biological treatment technique), helping organizations achieve the overall sustainability goals.

De la Torre Bayo et al. (Contribution 5) considered the circular economy to be a new model of waste management through energy self-sufficiency and valorization, which can be applied to wastewater treatment plants (WWTPs). They compared current landfill disposal with the production of densified and non-densified solid recovered fuel (SRF) using solar and thermal drying (by proposing five scenarios) in terms of environmental benefits, including waste reduction, resource conservation, and reduced greenhouse gas emissions, using the life cycle assessment (LCA) methodology through SimaPro 9.2. software. Their results show that among the waste management options evaluated, landfilling has the most harmful environmental impact. This is due to the release of various contaminants, such as heavy metals, organic pollutants and greenhouse gases, during the decomposition of screening waste in landfill that can have significant impacts on air, water and soil quality, as well as on human health and ecosystems. Considering the above, the results of the study emphasize the need to move away from landfilling and towards more sustainable waste management practices.

The research conducted by Solmaz (Contribution 6) presented findings on the removal of methylene blue (MB) and eriochrome black T (EBT) dyes using waste derived from Anatolian black pine cones (*Pinus nigra* Arn) (PC-PnA). Pine waste is recognized in the literature as being among the potentially valuable types of waste for the disposal of environmental contaminants, without having a commercial value. The study thoroughly examined the effects of pH, adsorbent dosage, contact time, the initial concentration of the specified dyes, and temperature on the adsorption capacity and removal efficiency of MB and EBT dyes by PC-PnA. The results showed that the maximum adsorption capacities for MB and EBT were 91.46 mg/g and 15.85 mg/g, respectively, at a pH of 3.0, a temperature of 25 °C, and after a contact time of 60 min. Furthermore, the analysis of isothermal, kinetic, and thermodynamic parameters indicated that the adsorption process followed pseudo-second-order kinetics. The data best fit the Langmuir isotherm model, and the adsorption process was identified as endothermic. These findings suggest that pine cone powder is a viable alternative sorbent for the removal of the MB and EBT dyes within the framework of sustainability.

In this Editorial, we aimed to emphasize the contribution of each article included in this Special Issue, highlighting each author's unique expertise in the field of Environmental Engineering and Management through the application of environmentally friendly processes and the use of sustainable materials for the removal of persistent pollutants from contaminated environments and their subsequent implications for a sustainable future.

Funding: This work was supported by a grant from the Romanian Ministry of Research, Innovation and Digitization, CNCS/CCCDI-UEFISCDI, project number PN-III-P2-2.1-PED-2019-2430, contract no. 439 PED/2020, within PNCDI III.

Acknowledgments: The Guest Editors sincerely express their appreciation to all the authors who contributed to the success of this Special Issue with all their hard work, as well as to the expert reviewers for their comments and suggestions made to ensure the high quality of both the manuscripts and this Special Issue. We also express our gratitude to the Editorial Team of *Processes* for their valuable support. "Ion Ionescu de la Brad" Iasi University of Life Sciences, Romania, is also acknowledged for its continuous support during the implementation of project number PN-III-P2-2.1-PED-2019-2430, contract no. 439 PED/2020.

Conflicts of Interest: The authors declare no conflicts of interest.

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