A Comprehensive Strategy for Activated Sludge Wastewater Treatment Facilities for Nutrient Removal Treatment

Abderrazzak Ihouaten[1], *Khadija* El-Moustaqim[2] [0009-0007-9193-6638], *Ahmed Abarkan* [3], *Karima* Azoulay[1], *Aziza Lamchaimech* [1], *Ahmed* Moufti[4] and *Jamal* Mabrouki[1] [0000-0002-3841-7755]

[1] Laboratory of Spectroscopy, Molecular Modelling, Materials, Nanomaterials, Water and Environment, CERN2D, Mohammed V University in Rabat, Faculty of Science, AV Ibn Battouta, Agdal, Rabat 10106, Morocco.
[2] Improvement and Valuation of Plant Resources, Faculty of Sciences, Ibn Tofaïl University—KENITRA-University Campus, Kenitra 14000, Morocco
[3] Biotarde,31120 Toulouse, France
[4] Regional Center for Education and Training Professions. Department of Physic and Chemistry. Team: Modelling in Physical Sciences. Casablanca-Settat. Morocco

Abstract. Traditional wastewater processing systems employ techniques that require a very lot of energy, so we need to get creative about doing that better and more sustainable. Activated sludge, which is found in many places around the world as a method of cleaning wastewater, is essential for removing nitrogen and phosphate. Proponents of these approaches will argue that traditional nutrient recovery methods (such as those based on physical, chemical and biological processes) are not necessarily "renewable" nor energy-efficient long-term solutions because they rely on destabilizing bio-nutrients rather than harvesting them, take a lot more energy to work through a thicker and different feed stock photo list and possess a variety of influent characteristics. In the situation, to simply optimize the biology process or operation will not satisfy new stringent discharge standards. The present study offers a complete and integrated approach for nutrient removal in activated sludge WWTPs. The developed framework includes the advanced monitoring and control strategy design along with system configuration selection and critical operating parameter optimization to improve biological N&P removal performances.

1 Introduction

The discharge of nitrogen and phosphorus from urban sewage treatment plants is an important environmental problem due to its direct result-causing water eutrophication, when they cause harmful algal blooms and aquatic ecosystem degradation [1]. As cities as well as the population grow wastewater treatment plants have to manage higher hydraulic and organic loads, while addressing stricter environmental laws regarding nutrient discharges [2]. Biological treatment is an attractive alternative to chemical approaches to address nitrogen, and phosphorus in wastewater. This is because there has been a rise in demand toward op-erating with lower value, low nutrient from concentration [3]. Activated sludge systems remain the most widely used biological treatment method for municipal wastewater due to their relatively high treatment efficiency and operational flexibility [4]. The last few decades have seen a significant advancement in the development of biological methods for removing nutrients, particularly phosphorus and nitrogen [5], [6]. However, the efficacy of numerous operational plants is still limited by unpredictable influent, operationally bad practice and increasing energy requirements [7], [8], [9], [10]. When it comes to nutrients removal, there are several conventional approaches that typically look into the process design, microbial population dynamics, and/or chemicals substitution [11], [12], [13], [14]. While those techniques have achieved some success, they frequently do not provide a comprehensive picture that spans design, operation and control. As a result, the treatment performance does not tend to be stable in response to a load change and treatment costs may significantly increase [10], [13], [15].

The goal of this article is to suggest a certain approach to nutrient removal in WTP employing activated sludge. The proposed approach includes the advanced monitoring and control strategies, process-design alternatives, better operating windows and basic biological knowledge. This approach aims at increasing treatment capacity, maximizing nutrient removal efficiency and sustainability of the wastewater treatment plant as well.

2 Principles of Activated Sludge Systems' Nutrient Removal

Natural-based instead of chemical methods for nitrogen and phosphorus removal from wastewater are receiving considerable interest (Figure. 1). This is attributed to the increasing need for low-cost wastewater denitrification. To approach the low-carbon age, it is necessary to utilize new wastewater treatment processes with nutrient recovery and reduced power consumption including CO_2 emission [16], [17]. From this point of view, the activated sludge (AS) process as one of the dominant treatment systems now to be used some such problems. For instance, full elimination of nitrogen from ammonium necessitates complete nitrification and denitrification, operation which demands much aeration and expensive carbon addition [18], [19] (**Fig. 2**).

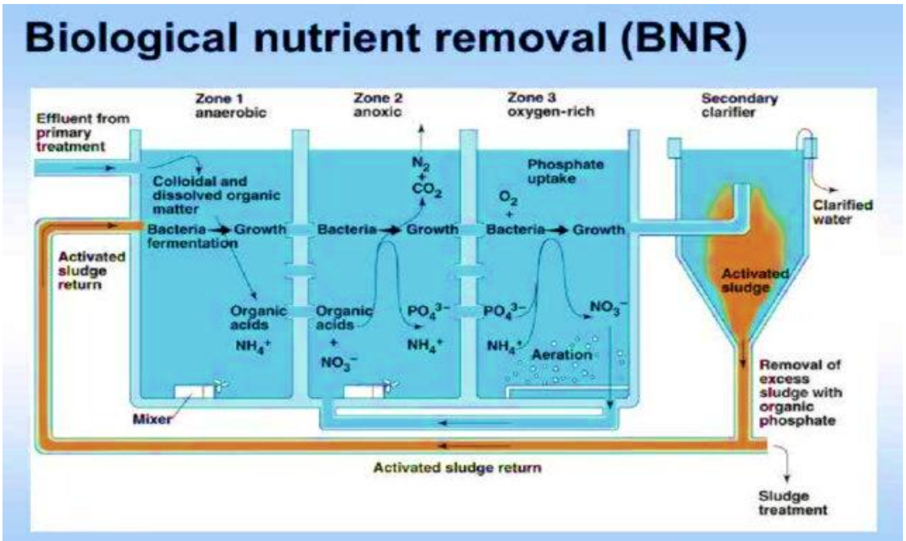

Fig. 1. Biological nutrient removal (BNR) process *[20]*.

2.1 Mechanisms Nitrogen Removal

The two primary stages of the biological nitrogen removal process in activated sludge systems are nitrification and denitrification. In the aerobic nitrification process, autotrophic microbes convert ammonia to nitrite and subsequently to nitrate [3]. This process is significantly impacted by temperature, pH, solids retention time, and dissolved oxygen concentration. Inadequate control of these variables could lead to ammonia breakthrough and partial nitrification in the wastewater [21], [22]. During anoxic denitrification heterotrophic bacteria utilize organic carbon as a source of free electrons to reduce nitrate to nitrogen gas. Quickly Biodegradable carbon source and appropriate anoxia are important to give a good performance of denitrification [23]. However, poor carbon source availability is a major limiting factor for many wastewater treatment plants and substantial energy or operational input must often be made to ensure complete N-removal [22], [24].

2.2 Phosphorus Removal Mechanisms

In systems with activated sludge, phosphorus can be taken out by chemical precipitation, biological uptake, or a mix of the two. The enhanced biological phosphorus removal is based on the activity of organisms that accumulate phosphorus by taking in more than they need for their metabolism in both anaerobic and aerobic conditions. During the anaerobic phase, these microorganisms release phosphorus and store volatile fatty acids as polymers inside their cells [25]. These microorganisms let out phosphorus and store volatile fatty acids as intracellular polymers during the anaerobic phase [26]. During the next aerobic phase, they take up more phosphorus than they release, which causes net phosphorus removal through sludge wasting. To work, this process needs to be strictly controlled so that there are no anaerobic conditions, enough volatile fatty acids are available, and oxygen and nitrate can't get into anaerobic areas [27].

3 Enhanced Nutrient Removal Process Configurations

Changes in the composition of influent and competition with different microbial communities are two things that can often affect biological phosphorus removal. It needs to be part of a bigger operational plan to work well over the long term [28]. The main goal of anaerobic–oxic arrangements is to remove phosphorus, however because of low anoxic volume, they frequently show poor nitrogen removal [29]. By adding specific denitrification zones, anaerobic-anoxic-oxic systems enhance nitrogen removal; nevertheless, their effectiveness is still influenced by carbon availability and internal recirculation rates (**Table 1**) [30].

Table 1. Activated sludge process configurations for enhanced biological nutrient removal.

Configuration	Primary nutrient removal mechanisms	Performance aspects	Refs
Anaerobic–Oxic (AO)	Biological phosphorus removal via anaerobic release and aerobic uptake; limited denitrification	Effective for phosphorus removal; nitrogen removal typically limited without dedicated anoxic zone	[31]
Anaerobic–Anoxic–Oxic (A2O)	Combined phosphorus removal and sequential nitrification–denitrification	Improved nitrogen removal compared to AO when internal recirculation is properly managed	[32]

Three-stage Bardenpho	Extended denitrification and nitrification steps with PAO activity	Higher total nitrogen and phosphorus removal potential than simple A2O; greater operational control required	[32]
UCT (University of Cape Town)	Similar to Bardenpho with modified internal recycle to enhance phosphorus removal	Robust phosphorus removal with operational flexibility; N removal varies with configuration	[32]
UCT Modified (UCTM)	Further modification of UCT flow patterns to optimize N and P pathways	Improved performance under influent variability compared to standard UCT	[32]

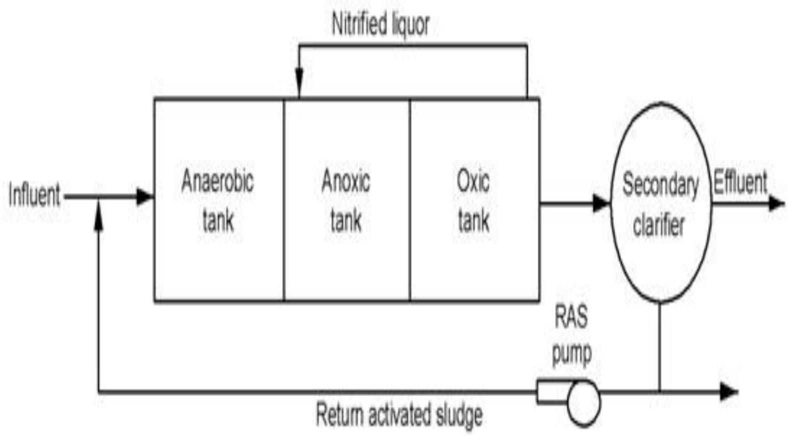

Fig. 2. A typical flowchart showing the combination of processes involved.

By combining several anoxic and aerobic zones, more intricate configurations such as four-stage or five-stage systems offer increased flexibility and nutrient removal capacity [33]. These systems can't be used in small or resource-constrained institutions, though, because they need more capital investment and strict operational supervision. Setting up the process is important for getting rid of nutrients, but it doesn't guarantee the best performance on its own [34]. Recent improvements in biological wastewater treatment have led to the creation of new modifications that are meant to make the process more efficient and environmentally friendly. However, it is still hard to optimize parameters, make technology big enough for industrial application, and keep costs down [35], [36], [37].

4 Performance Evaluation and Environmental Benefits

In order to regulate nitrogen and phosphorus from municipal wastewater treatment and reclamation plants in the aquatic environment, biological nutrient removal is essential [38]. Recent developments demonstrate the potential of microbial community analysis to enhance energy performance and treatment efficiency in WWTPs. According to studies, certain microbial species play a major role in the biological processes that remove nutrients. The activated sludge process is a well-liked biological treatment method that effectively eliminates organic materials, nutrients, and other impurities from municipal wastewater. This process involves adding a culture of microorganisms to the wastewater, which accelerates the organic material's breakdown [39]. Biological N removal technology is the microbial transformation of organic nitrogen into endogenous nitrogen that is assimilated into the tissues or cellular components of microorganisms. It also explains how, in anoxic or aerobic conditions, organic nitrogen is converted into smaller inorganic nitrogen molecules, which subsequently transform into gaseous nitrogen compounds released into the atmosphere [40], [41].

5 Challenges and Future Perspectives

The Cyclic Activated Sludge Process is a cyclical operation with significant advantages including reduction of nutrients, lower energy consumption and generally a stable process for wastewater treatment, although the cost to operate, the ability to implement technology to do business and knowing what to choose as optimal process conditions present notable challenges [42]. These obstacles include the capital cost of high tech equipment, the need for trained personnel and the integration of the process into existing systems [43]. Overall, the continual advancement of cyclical activated sludge processes has a tremendous potential to develop efficient, sustainable technologies for the treatment of wastewater and is essential to reducing water pollution and conserving environmental resource [44]. It is important to carefully monitor and manage several variables when biological N and P removal along with resource recovery techniques to maintain stable and effective treatment processes. A number of factors involved in the operation of this type of treatment process are interrelated; therefore, maintaining the stability of the system and preventing large fluctuations in load during operation is one of the key challenges associated with implementing this technology [45]. Phosphorus recovery and energy-neutral wastewater treatment are two resource recovery techniques that appear promising for next-generation treatment facilities [46], [47-51].

6 Conclusion

Sustainable development is supported by a water treatment technology that reduces energy consumption; improves the quality of the treated water and converts contaminants from waste products to resources. Over the years, researchers have developed new methods to grow activated sludge (biological) processes to treat wastewater containing organic and inorganic contaminants (phenols). This paper will focus on the complete method developed to remove nutrients from activated sludge treatment plants, including advanced control systems, operational optimizations, and process configurations. Future research should focus on combining microbial engineering and intelligent monitoring, improve reactor designs, and explore new methods for resource reclamation and pollution removal. This method is expected to facilitate efficient resource recycling and enhance global water resource management and ecological conservation.

References

[1] H. Yu, J. Kim, et C. Lee, « Nutrient removal and microalgal biomass production from different anaerobic digestion effluents with Chlorella species », *Scientific reports*, vol. 9, nº 1, Art. nº 1, 2019.

[2] M. A. Oturan, « Traitement des micropolluants organiques dans l'eau par des procédés d'oxydation avancée ».

[3] L. Delgadillo-Mirquez, F. Lopes, B. Taidi, et D. Pareau, « Nitrogen and phosphate removal from wastewater with a mixed microalgae and bacteria culture », *Biotechnology Reports*, vol. 11, p. 18-26, sept. 2016, doi: 10.1016/j.btre.2016.04.003.
[4] N. Moondra, N. D. Jariwala, et R. A. Christian, « Sustainable treatment of domestic wastewater through microalgae », *International Journal of Phytoremediation*, vol. 22, nº 14, Art. nº 14, déc. 2020, doi: 10.1080/15226514.2020.1782829.
[5] K. El-Moustaqim, J. Mabrouki, et M. Azrour, « Monitoring of Water Toxicity Through the Internet of Things to Protect the Health of the Population », 2023, p. 85-92. doi: 10.1201/9781003430735-7.
[6] K. El-Moustaqim *et al.*, « Combination of Microalgae Method, Decantation, and Filtration for Domestic Wastewater Treatment », *Sustainability*, vol. 15, nº 22, Art. nº 22, janv. 2023, doi: 10.3390/su152216110.
[7] K. El-Moustaqim, M. Benchrifa, J. Mabrouki, et D. Hmouni, « Interaction between the Microalgae Cultivation System and Its Effects on Nutrient Removal from Wastewater », 2024, p. 70-79. doi: 10.1201/9781003436218-8.
[8] K. El-Moustaqim, J. Mabrouki, M. Azrour, M. Hadine, et D. Hmouni, « Enabling Smart Agriculture Through Integrating the Internet of Things in Microalgae Farming for Sustainability », in *Smart Internet of Things for Environment and Healthcare*, M. Azrour, J. Mabrouki, A. Alabdulatif, A. Guezzaz, et F. Amounas, Éd., Cham: Springer Nature Switzerland, 2024, p. 209-222. doi: 10.1007/978-3-031-70102-3_15.
[9] K. El-Moustaqim, J. Mabrouki, A. Ghailane, C. Lamiri, et D. Hmouni, « Advancing Environmental Sustainability », 2025, p. 176-188. doi: 10.1201/9781003647263-16.
[10] K. El-Moustaqim, J. Mabrouki, et D. Hmouni, « Valorization of Agro-Industrial Wastewater for Microalgae Cultivation », 2025, p. 569-584. doi: 10.4018/979-8-3693-9450-2.ch029.
[11] K. El-Moustaqim, A. Tallou, J. Mabrouki, M. Slaoui, et D. Hmouni, « Phytoremediation Processes for the Removal of Heavy Metals », 2024, p. 33-46. doi: 10.1007/978-3-031-55787-3_3.
[12] K. El-Moustaqim, S. E. Sbai, J. Mabrouki, et D. Hmouni, « Critical review of green microalgal biomass development through CO2 sequestration », *Euro-Mediterr J Environ Integr*, mai 2024, doi: 10.1007/s41207-024-00548-6.
[13] K. El-Moustaqim, S. E. Sbai, Y. El Yousfi, J. Mabrouki, et D. Hmouni, « New strategy for the advancement of modern agriculture through the use of microalgae as biofertilizers », *Euro-Mediterr J Environ Integr*, oct. 2024, doi: 10.1007/s41207-024-00678-x.
[14] K. El-Moustaqim, T. Rachiq, I. Bencheikh, J. Mabrouki, et D. Hmouni, « Environmental Assessment of Microalgal Biomass Fermentation for Green Hydrogen Production », 2025, p. 129-142. doi: 10.4018/979-8-3693-8980-5.ch009.
[15] J. Yang *et al.*, « Phytoremediation potential evaluation of three rhubarb species and comparative analysis of their rhizosphere characteristics in a Cd- and Pb-contaminated soil », *Chemosphere*, vol. 296, p. 134045, juin 2022, doi: 10.1016/j.chemosphere.2022.134045.
[16] X. Chen, Z. Hu, Y. Qi, C. Song, et G. Chen, « The interactions of algae-activated sludge symbiotic system and its effects on wastewater treatment and lipid accumulation », *Bioresource Technology*, vol. 292, p. 122017, nov. 2019, doi: 10.1016/j.biortech.2019.122017.
[17] O. Nybroe, P. E. Jørgensen, et M. Henze, « Enzyme activities in waste water and activated sludge », *Water Research*, vol. 26, nº 5, Art. nº 5, mai 1992, doi: 10.1016/0043-1354(92)90230-2.

[18] J. J. W. Hulsbeek, J. Kruit, P. J. Roeleveld, et M. C. M. Van Loosdrecht, « A practical protocol for dynamic modelling of activated sludge systems », *Water Science and Technology*, vol. 45, nº 6, Art. nº 6, 2002.
[19] A. M. Karpinska et J. Bridgeman, « CFD-aided modelling of activated sludge systems–A critical review », *Water research*, vol. 88, p. 861-879, 2016.
[20] A. Grdulska et R. Kowalik, « ESTROGEN REMOVAL FROM WASTEWATER », *Structure and Environment*, vol. 12, p. 133-141, sept. 2020, doi: 10.30540/sae-2020-014.
[21] K. Flores-Zambrano, W. Tapia, et P. Castillejo, « Microalgae Strains Isolated from Piggery Wastewater in Ecuador: Effective Nitrogen Compound Removal and Growth Potential in Extremophile Conditions », *Biotechnology Reports*, p. e00883, 2025, Consulté le: 24 mars 2025. [En ligne]. Disponible sur: https://www.sciencedirect.com/science/article/pii/S2215017X25000104
[22] P. Ma *et al.*, « Evaluating Growth and Nitrogen and Phosphorus Removal of Four Microalgae in Different Nutrient Concentrations », *Biology*, vol. 14, nº 9, p. 1155, sept. 2025, doi: 10.3390/biology14091155.
[23] S. Aslan et I. K. Kapdan, « Batch kinetics of nitrogen and phosphorus removal from synthetic wastewater by algae », *Ecological Engineering*, vol. 28, nº 1, Art. nº 1, nov. 2006, doi: 10.1016/j.ecoleng.2006.04.003.
[24] F. M. Ortega-Blas, J. C. Ramos-Saravia, et P. L. Cossío-Rodríguez, « Removal of Nitrogen and Phosphorus from Municipal Wastewater Through Cultivation of Microalgae Chlorella sp. in Consortium », *Water*, vol. 17, nº 8, p. 1160, janv. 2025, doi: 10.3390/w17081160.
[25] A. Manas Llamas, « Phosphorus removal and induced precipitation in aerobic granular sludge process for wastewater treatment ». Consulté le: 9 octobre 2025. [En ligne]. Disponible sur: https://theses.hal.science/tel-04240396
[26] L. Wang, J. Liu, Q. Zhao, W. Wei, et Y. Sun, « Comparative study of wastewater treatment and nutrient recycle via activated sludge, microalgae and combination systems », *Bioresource Technology*, vol. 211, p. 1-5, juill. 2016, doi: 10.1016/j.biortech.2016.03.048.

[27] E. Vaiopoulou, P. Melidis, et A. Aivasidis, « An activated sludge treatment plant for integrated removal of carbon, nitrogen and phosphorus », *Desalination*, vol. 211, nº 1, p. 192-199, juin 2007, doi: 10.1016/j.desal.2006.02.092.
[28] J. Derco, A. Žgajnar Gotvajn, P. Gul'ašová, A. Kassai, et N. Šoltỳsová, « Nutrient removal and recovery from municipal wastewater », *Processes*, vol. 12, nº 5, p. 894, 2024, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.mdpi.com/2227-9717/12/5/894
[29] D. Parde, R. Ghosh, P. Rajpurohit, S. Bhaduri, et M. Behera, « Nutrient Retrieval Techniques in Wastewater Treatment », in *Biological and Hybrid Wastewater Treatment Technology*, M. M. Ghangrekar, S. Yadav, et R. N. Yadava, Éd., in Earth and Environmental Sciences Library. , Cham: Springer Nature Switzerland, 2024, p. 159-195. doi: 10.1007/978-3-031-63046-0_7.
[30] M. A. Díaz *et al.*, « Excess of Nutrients in Prefabricated or Compact Wastewater Treatment Plants: Review, Solution Alternative, and Modeling for Verification », *Water*, vol. 16, nº 10, p. 1354, 2024, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.mdpi.com/2073-4441/16/10/1354?utm_campaign=releaseissue_waterutm_medium=emailutm_source=releaseissueutm_term=doilink33

[31] J. Derco, A. Žgajnar Gotvajn, P. Guľašová, A. Kassai, et N. Šoltýsová, « Nutrient Removal and Recovery from Municipal Wastewater », *Processes*, vol. 12, nº 5, p. 894, mai 2024, doi: 10.3390/pr12050894.
[32] E. Ramin *et al.*, « Plant-wide assessment of alternative activated sludge configurations for biological nutrient removal under uncertain influent characteristics », *Science of The Total Environment*, vol. 822, févr. 2022, doi: 10.1016/j.scitotenv.2022.153678.
[33] G. Mannina *et al.*, « The effect of aeration mode (intermittent vs. continuous) on nutrient removal and greenhouse gas emissions in the wastewater treatment plant of Corleone (Italy) », *Science of The Total Environment*, vol. 924, p. 171420, 2024, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.sciencedirect.com/science/article/pii/S0048969724015614
[34] C. Xiu et L. Dong, « Design of sewage treatment monitoring system based on internet of things », in *2019 Chinese Control And Decision Conference (CCDC)*, IEEE, 2019, p. 960-964.
[35] J.-J. Su, S.-T. Ding, et H.-C. Chung, « Establishing a smart farm-scale piggery wastewater treatment system with the internet of things (IoT) applications », *Water*, vol. 12, nº 6, Art. nº 6, 2020.
[36] H. Sarma, N. F. Islam, R. Prasad, M. N. V. Prasad, L. Q. Ma, et J. Rinklebe, « Enhancing phytoremediation of hazardous metal(loid)s using genome engineering CRISPR–Cas9 technology », *Journal of Hazardous Materials*, vol. 414, p. 125493, juill. 2021, doi: 10.1016/j.jhazmat.2021.125493.
[37] L. S. Pérez-Mora *et al.*, « Phycoremediation Processes for Secondary Effluent from Sewage Treatment Plants Using Photosynthetic Microorganisms: A Review », *Applied Microbiology*, vol. 3, nº 2, Art. nº 2, avr. 2023, doi: 10.3390/applmicrobiol3020028.
[38] G. Zhou *et al.*, « Environmental application of molasses-based foam dust suppressant: Preparation, performance evaluation and mechanism analysis », *Construction and Building Materials*, vol. 458, p. 139541, 2025, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.sciencedirect.com/science/article/pii/S095006182404683X
[39] L. Wang, L. Chen, P. Gao, et C. Li, « Construction and Application of Carbon Performance Evaluation Index System for Chinese Industrial Enterprises From the Perspective of Low-Carbon Transition », *J of Intl Development*, vol. 37, nº 3, p. 736-757, avr. 2025, doi: 10.1002/jid.3984.
[40] D. Cai *et al.*, « Performance evaluation of stabilized soils with selected common waste materials of rice husk ash, steel slag and iron tailing powder », *Materials*, vol. 18, nº 2, p. 346, 2025, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.mdpi.com/1996-1944/18/2/346
[41] M. Ferrazzi, W. Li, G. L. Tortorella, F. Costa, et A. Portioli-Staudacher, « Assessing the environmental benefits of lean practices in the manufacturing industry: An Interpretive Ranking Process analysis », *Journal of Cleaner Production*, vol. 525, p. 146405, 2025, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.sciencedirect.com/science/article/pii/S095965262501755X
[42] M. Mosaferi *et al.*, « A comprehensive review of cyclic activated sludge processes in wastewater treatment: Current perspectives and future challenges », *Sustainable Chemistry for the Environment*, vol. 9, p. 100191, 2025, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.sciencedirect.com/science/article/pii/S2949839224001342
[43] Q. Song, Y. Hua, Y. Yu, C. Chen, B. Wu, et X. Dai, « Impediments to bioaccessibility in the anaerobic digestion of waste activated Sludge: An in-depth

review of challenges and influencing factors », *Energy & Environmental Sustainability*, vol. 1, nº 2, p. 100026, 2025, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.sciencedirect.com/science/article/pii/S3050745625000252

[44] M. N. I. Siddique, P. Hedĕnec, M. Syarifuddin, S. I. Yahya, et M. Z. B. Ibrahim, « The Influence of Carbon Compounds on Anaerobic Performance: Challenges & Perspectives », Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.researchgate.net/profile/Md-Nurul-Islam-Siddique/publication/389490290_The_Influence_of_Carbon_Compounds_on_Anaerobic_Performance_Challenges_Perspectives/links/67c3da0696e7fb48b9d56661/The-Influence-of-Carbon-Compounds-on-Anaerobic-Performance-Challenges-Perspectives.pdf

[45] S. Niju, V. Shruthi, et K. Priyadharshini, « Comprehensive Insights into Biological and Bio-Electrochemical Treatment of the Sago Industry Wastewater: Challenges and Future Perspectives », *Sustainable Chemistry for the Environment*, p. 100242, 2025, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.sciencedirect.com/science/article/pii/S2949839225000379

[46] A. Monroy-Licht *et al.*, « Biological approaches to mitigate heavy metal pollution from battery production effluents: advances, challenges, and perspectives », *Environ Sci Pollut Res*, vol. 32, nº 35, p. 20844-20878, sept. 2025, doi: 10.1007/s11356-025-36792-8.

[47] G. S. Zagui *et al.*, « Municipal sewage as a pathway for multidrug-resistant KPC-producing Klebsiella pneumoniae from hospital effluent to urban stream: challenges for wastewater management », *International Journal of Hygiene and Environmental Health*, vol. 269, p. 114640, 2025, Consulté le: 25 décembre 2025. [En ligne]. Disponible sur: https://www.sciencedirect.com/science/article/pii/S1438463925001221

[48] Ghizlane, F., Mabrouki, J., Ghrissi, F., & Azrour, M. (2022). Proposal for a high-resolution particulate matter (PM10 and PM2. 5) capture system, comparable with hybrid system-based internet of things: case of quarries in the western rif, Morocco. Pollution, 8(1), 169-180.

[49] Benchrifa, M., Elouardi, M., Fattah, G., Mabrouki, J., & Tadili, R. (2023). Identification, simulation and modeling of the main power losses of a photovoltaic installation and use of the internet of things to minimize system losses. In Advanced technology for smart environment and energy (pp. 49-60). Cham: Springer International Publishing.

[50] Mgalaa, S., Mabrouki, J., Elouardi, M., El Azzouzi, L., Moufti, A., El Hajjaji, S., ... & El Belghiti, M. A. (2022). Study and evaluation of the degradation of procion blue dye by the ozonation method: parametric and isothermal study. Nanotechnology for Environmental Engineering, 7(3), 691-697.

[51] Rachiq, T., Abrouki, Y., Mabrouki, J., Samghouli, N., Fersi, C., Rahal, S., & El Hajjaji, S. (2021). Evaluation of the efficiency of different materials to remove specific pollutants from landfill leachate. Desalination and Water Treatment, 238, 240-250.