

Development of Membrane Bioreactors (MBR) for Sustainable Urban Wastewater Treatment

Anthonia Chinyere Nwachi¹, Emmanuel Amobi Nwakaeze¹, Iroha Ifeanyichukwu Romanus¹

¹ Ebonyi State University
PMB 053, Abakaliki, Nigeria

DOI: [10.22178/pos.117-30](https://doi.org/10.22178/pos.117-30)

LCC Subject Category: T1-995

Received 26.04.2025
Accepted 24.05.2025
Published online 31.05.2025

Corresponding Author:
Anthonia Chinyere Nwachi
anthonia.nwachi@ebsu.edu.ng

© 2025 The Authors. This article is licensed
under a [Creative Commons Attribution 4.0](https://creativecommons.org/licenses/by/4.0/)
License 

Abstract. The growing demand for efficient and sustainable wastewater treatment solutions in urban areas has positioned membrane bioreactors (MBRs) as a promising alternative to conventional treatment systems. This study explores the development, optimisation, and application of MBR technology for urban wastewater management. Combining biological degradation with membrane filtration, MBRs offer superior effluent quality, compact footprint, and the potential for water reuse, making them ideal for space-constrained urban settings. The research focuses on recent advances in membrane materials, fouling mitigation strategies, energy efficiency, and system integration with decentralised treatment frameworks. Researchers evaluate performance using pilot-scale and full-scale MBR systems, emphasising nutrient removal, sludge characteristics, operational stability, and lifecycle costs. The findings demonstrate that MBRs can significantly contribute to achieving circular water economy goals in urban environments, supporting environmental protection and resource recovery. The authors also discuss recommendations for policy and future research directions.

Keywords: Membrane Bioreactor; Urban Wastewater Treatment; Sustainable Water Management; Membrane Fouling; Water Reuse.

INTRODUCTION

The global urbanisation has intensified the demand for effective wastewater treatment solutions. Urban centres, characterised by high population densities and industrial activities, generate substantial volumes of wastewater that, if inadequately treated, pose significant environmental and public health risks. Harmful chemicals in wastewater negatively affect aquatic organisms, degrade soil fertility, threaten water resources, and disrupt overall ecosystem balance [1]. These substances have been associated with numerous health problems. There has been extensive research on PFAS contamination and its effects globally [2]. While effective to a degree, traditional wastewater treatment methods often fall short in addressing the complexities of modern urban effluents and the stringent discharge standards now in place [3]. Challenges persist, including insufficient treatment methods, poor operational and maintenance practices, and the disposal of membranes contaminated with

PFAS [2]. Introducing pollutants, such as heavy metals, pesticides, and pathogens, into water sources poses significant health risks [4].

In response to these challenges, membrane bioreactor (MBR) technology has emerged as a promising alternative. MBRs integrate biological degradation processes with membrane filtration, offering enhanced effluent quality and operational efficiency. This integration removes organic and inorganic contaminants, making MBRs suitable for treating complex urban wastewater streams [5]. MBRs offer several advantages over conventional treatment systems. These include a smaller footprint, higher biomass concentration, and superior effluent quality, collectively contributing to their suitability in space-constrained urban environments.

Furthermore, MBRs facilitate water reuse applications, aligning with the principles of sustainable water management and circular economy [6]. Despite their advantages, MBRs are not without challenges. Membrane fouling remains a signifi-

cant issue, increasing operational costs and maintenance requirements. However, recent advancements in membrane materials and fouling mitigation strategies have shown promise in addressing these concerns. Innovations, such as the development of antifouling membranes and the application of advanced cleaning protocols, are enhancing the viability of MBRs in urban settings [7]. Integrating MBRs into urban wastewater treatment frameworks supports sustainable development objectives, particularly in achieving clean water and sanitation goals. By enabling water reuse and resource recovery, MBRs contribute to reducing the environmental footprint of urban wastewater management. Moreover, their adaptability to decentralised treatment systems makes them a versatile solution for diverse urban contexts [8]. This review aims to provide a comprehensive overview of the development and application of MBR technology in urban wastewater treatment. It will explore recent advancements in membrane materials, fouling control strategies, and system integration approaches. Additionally, the review will assess the performance of MBRs in pilot and full-scale operations, considering factors such as nutrient removal efficiency, sludge characteristics, and lifecycle costs. By synthesising current research and practical experiences, this review seeks to inform future developments and policy directions in sustainable urban wastewater management.

RESULTS AND DISCUSSION

Principles of Membrane Bioreactor (MBR) Technology. Membrane Bioreactor (MBR) technology has significantly advanced wastewater treatment by combining biological degradation processes with membrane filtration to achieve high-quality effluent. This integration removes organic and inorganic contaminants, making MBRs suitable for treating complex urban wastewater streams [3]. The core principle of MBR technology lies in its ability to decouple hydraulic retention time (HRT) from solids retention time (SRT). This decoupling enables the maintenance of high biomass concentrations within the bioreactor, enhancing the degradation of organic pollutants and improving overall treatment efficiency [9]. The membrane component, typically microfiltration or ultrafiltration membranes, serves as a physical barrier, retaining suspended solids and

microorganisms while allowing treated water to pass through.

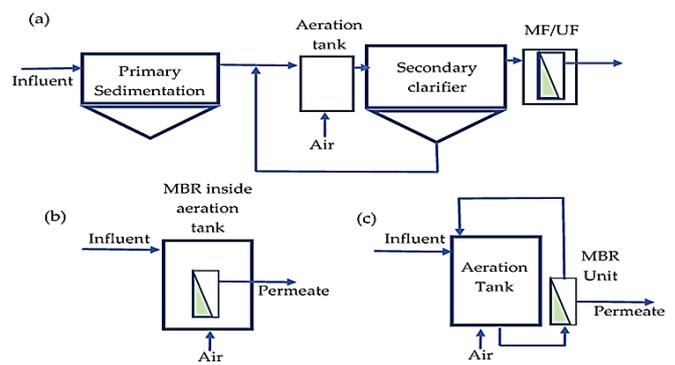


Figure 1 – Membrane Bioreactor (MBR) Technology Towards Sustainable Industrial Wastewater

Engineers generally categorise MBRs into submerged (immersed) and side stream systems. In submerged MBRs, the system immerses the membranes directly in the bioreactor, and filtration occurs due to transmembrane pressure created by gravity or suction. This configuration is energy efficient and has become prevalent in municipal wastewater treatment applications [10]. Conversely, side-stream MBRs involve the circulation of mixed liquor from the bioreactor through external membrane modules, typically requiring a higher energy input due to the need for pumping but offering easier membrane maintenance and replacement [11]. The operational parameters of MBR systems, such as hydraulic retention time (HRT), solids retention time (SRT), mixed liquor suspended solids (MLSS) concentration, and transmembrane pressure (TMP), are crucial in determining system performance. Optimising these parameters ensures efficient pollutant removal, minimises membrane fouling, and extends membrane lifespan [10]. For instance, maintaining a high SRT allows the development of a specialised microbial community capable of degrading complex organic compounds. At the same time, appropriate TMP levels are essential to sustain consistent permeate flow rates without inducing excessive fouling [12]. MBR technology offers several advantages over conventional activated sludge processes, including superior effluent quality, a reduced footprint due to the elimination of secondary clarifiers, and the potential for water reuse applications. These benefits make MBRs particularly attractive for urban areas with limited space and stringent discharge standards [3]. However,

challenges such as membrane fouling, higher energy consumption, and operational costs need to be addressed to fully realise the potential of MBR systems in sustainable urban wastewater management [7].

Advances in Membrane Materials. The evolution of membrane materials has been pivotal in enhancing the performance and applicability of Membrane Bioreactor (MBR) systems for treating urban wastewater. While cost-effective and flexible, traditional polymeric membranes often have limitations, including fouling and limited chemical stability. Researchers have explored various materials and modifications to address these challenges to improve membrane properties.

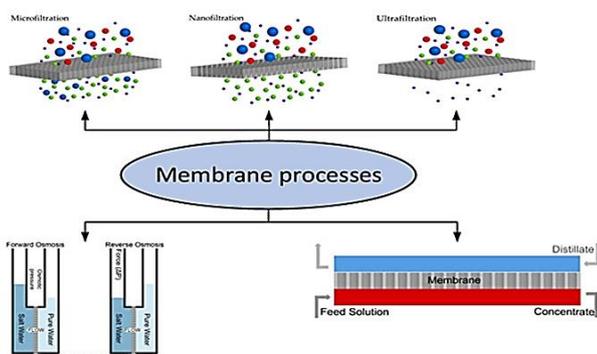


Figure 2 – Membrane Process

Ceramic membranes have garnered attention due to their superior mechanical strength, chemical resistance, and thermal stability. These attributes make them suitable for harsh wastewater treatment conditions. Moreover, ceramic membranes exhibit higher fouling resistance and longer lifespans than their polymeric counterparts, albeit at a higher initial cost [13].

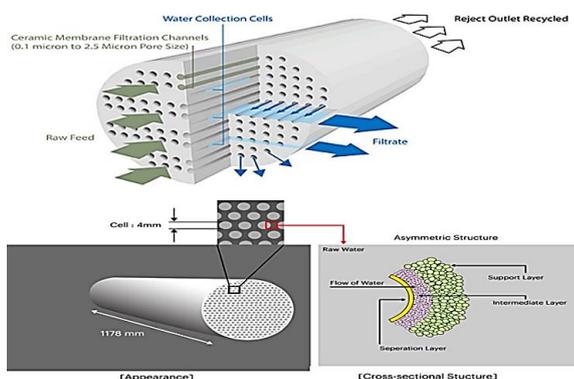


Figure 3 – Ceramic Membrane for wastewater filtration

Polymeric membranes, such as those made from polyvinylidene fluoride (PVDF) and polysulfone (PSU), remain widely used due to their affordability and ease of fabrication. However, their hydrophobic nature often leads to fouling issues. Surface modifications have enhanced hydrophilicity and reduced fouling propensity to mitigate this [14].

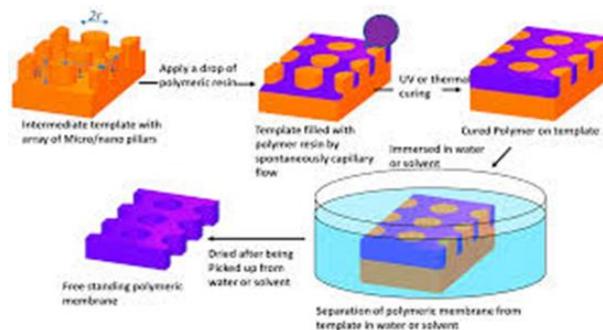


Figure 4 – Polymeric membrane

The development of nanocomposite membranes represents a significant advancement in membrane technology. These membranes exhibit improved permeability, selectivity, and antifouling properties by incorporating nanomaterials like graphene oxide, carbon nanotubes, and metal oxide nanoparticles into polymer matrices. For instance, integrating graphene oxide has enhanced the membrane's hydrophilicity and antimicrobial activity, thereby reducing biofouling [15].

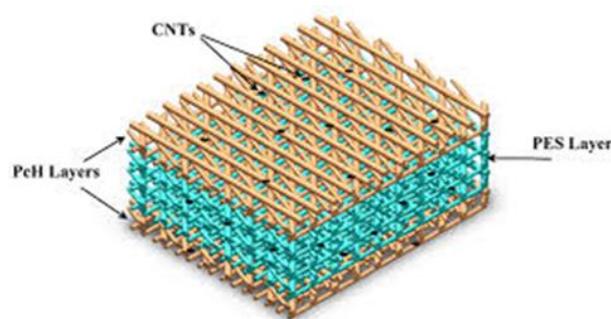


Figure 5 – Nanocomposite membrane

Surface modifications play a crucial role in tailoring membrane properties to meet specific application requirements. Techniques such as grafting hydrophilic polymers, coating with antifouling agents, and plasma treatment have improved membrane performance. For example, applying polydopamine coatings inspired by mussel adhe-

sive proteins has effectively enhanced membrane hydrophilicity and resistance to fouling [16].

In recent years, bio-inspired and smart membrane materials have emerged as innovative solutions for wastewater treatment. These materials draw inspiration from natural systems to achieve functionalities like self-cleaning and responsive behaviour. For instance, membranes incorporating stimuli-responsive polymers can alter their properties in response to environmental changes, optimising performance and reducing maintenance requirements [14]. The continuous advancement in membrane materials, encompassing ceramic, polymeric, nanocomposite, and bio-inspired designs, holds promise for developing more efficient and sustainable membrane bioreactor (MBR) systems. By addressing challenges related to fouling, permeability, and durability, these innovations contribute significantly to optimising urban wastewater treatment processes.

Membrane Fouling and Mitigation Strategies.

Membrane fouling remains one of the most persistent challenges in membrane bioreactor (MBR) operations, significantly reducing membrane lifespan and system efficiency. It can be categorised into four major types: biofouling, organic fouling, inorganic scaling, and particulate fouling [17].

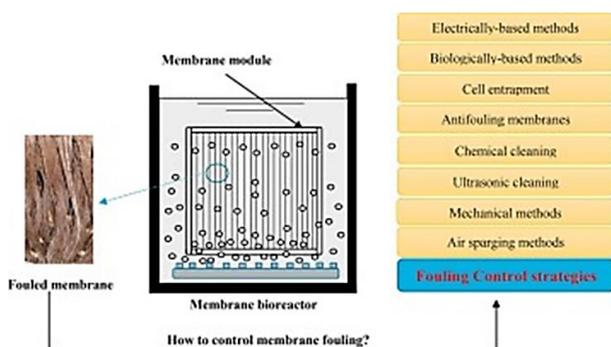


Figure 6 – Fouling mitigation strategies in membrane bioreactors

Biofouling is induced by microbial growth and biofilm formation on the membrane surface. Organic fouling is mainly due to the accumulation of soluble microbial products and natural organic matter. At the same time, the precipitation of salts like calcium carbonate and silicates causes inorganic fouling – conversely, partial fouling results from suspended solids and colloids [10]. Mitigation strategies for membrane fouling are

classified into physical, chemical, and biological methods. Physical techniques, such as backwashing and air scouring, are widely adopted due to their simplicity and cost-effectiveness [18]. When physical cleaning fails to restore membrane performance, chemical cleaning typically employs in-place cleaning (CIP) protocols using acids, alkalis, or oxidative agents. More recently, biological strategies like quorum quenching (QQ) have shown promise in preventing biofilm formation by disrupting bacterial communication [19]. Advanced innovations are helping to overcome fouling more sustainably. Antifouling membranes with modified surfaces, such as hydrophilic coatings or embedded nanoparticles, reduce microbial and organic adhesion [20]. Dynamic membranes, which form a cake layer over support media, are another novel approach offering cost efficiency and self-healing potential [13]. Furthermore, the immobilisation of QQ enzymes or bacteria on the membrane surface has significantly reduced biofouling in long-term studies [21].

Energy Efficiency and Operational Optimisation.

Energy consumption in MBR systems is typically higher than in conventional activated sludge (CAS) systems due to the continuous aeration required for biological treatment and membrane scouring. Studies show that MBRs can consume between 0.3 and 1.0 kWh/m³, compared to 0.2–0.6 kWh/m³ in CAS systems [22, 10]. Despite this, MBRs offer improved effluent quality, smaller footprints, and potential for water reuse, which can balance the higher energy demand in urban contexts. Enhancing energy efficiency has led to the development of energy membranes, better air distribution systems, and process intensification methods [23]. Innovations like intermittent aeration and granular sludge systems have also reduced aeration demands. Furthermore, optimising operational parameters such as sludge retention time (SRT) and hydraulic retention time (HRT) can significantly lower energy use without compromising treatment efficacy [24].

Integrating real-time monitoring and sensor technologies is another game changer in MBR operations. When coupled with machine learning algorithms, Internet of Things (IoT) systems enable the dynamic control of aeration and sludge management, thereby enhancing performance and energy efficiency [14]. These technologies enable predictive maintenance and rapid responses to system disturbances, ensuring opera-

tional stability and reducing unnecessary energy consumption.

Integrating Membrane Bioreactor (MBR) systems into urban wastewater infrastructure presents centralised and decentralised application opportunities.

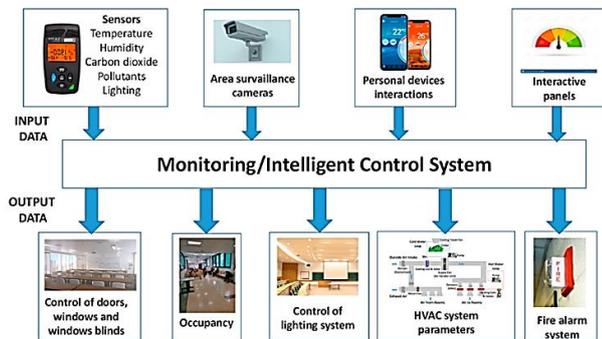


Figure 7 – Monitoring System in MBR operation

Centralised MBR systems are typically implemented in large-scale municipal wastewater treatment plants, offering economies of scale and centralised management. In contrast, decentralised MBR systems are designed for localised treatment, serving individual buildings or communities. Decentralised systems can reduce the burden on existing sewer networks and provide flexibility in urban planning [25].

Retrofitting existing wastewater treatment plants (WWTPs) with membrane bioreactor (MBR) technology is a viable strategy to enhance treatment performance and meet increasingly stringent effluent standards. Retrofitting involves replacing or upgrading components of conventional activated sludge systems with MBR modules, resulting in improved effluent quality and a reduced footprint [26]. Such upgrades can be cost-effective compared to constructing new facilities.

MBR systems also facilitate urban water reuse applications, including irrigation, toilet flushing, and industrial processes. The high-quality effluent produced by MBRs meets the stringent requirements for non-potable reuse, contributing to water conservation efforts in urban areas [27]. Implementing MBRs for water reuse can alleviate pressure on freshwater resources and support sustainable urban development.

Case Studies. Several pilot and full-scale implementations of MBR systems worldwide demonstrate their effectiveness in wastewater treat-

ment. For instance, the Henriksdal WWTP in Stockholm, Sweden, was upgraded to an MBR system, resulting in significant improvements in effluent quality. The plant reported removal efficiencies of over 95% for Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), as well as substantial reductions in Total Nitrogen (TN) and Total Phosphorus (TP) levels [28].

The economic analyses of MBR systems consider capital expenditures (CAPEX) and operational expenditures (OPEX). While MBRs may have higher initial costs than conventional systems, their operational efficiencies and superior effluent quality can result in favourable lifecycle costs. A study comparing MBR and conventional systems found that, despite higher capital expenditure (CAPEX), the MBR system had lower operating expenditure (OPEX) and a competitive pay-back period [29].

1) Environmental and Circular Economy Impacts. MBR systems contribute to environmental sustainability and the circular economy by enabling resource recovery and reducing ecological footprints. The reduced sludge production in MBRs lowers disposal requirements and associated greenhouse gas emissions. Additionally, MBRs facilitate the recovery of valuable resources such as biogas and phosphorus. Researchers or wastewater treatment facilities can recover phosphorus from wastewater sludge through chemical precipitation, producing fertilisers and reducing reliance on non-renewable phosphate sources [30].

Water reuse enabled by MBR systems closes the urban water loop, reducing the demand for freshwater extraction and mitigating the impacts of water scarcity. Life Cycle Assessments (LCAs) comparing MBRs to conventional activated sludge systems have shown that MBRs can have lower environmental impacts, particularly in energy consumption and greenhouse gas emissions, when optimised for energy efficiency and resource recovery [30].

2) Policy, Standards, and Future Prospects. The regulatory landscape for treated water reuse is evolving globally, with significant strides in establishing guidelines and standards. In the United States, the Environmental Protection Agency (EPA) has developed comprehensive guidelines to assist states in formulating water reuse standards, emphasising public health protection and environmental sustainability [31]. States like Cal-

ifornia have adopted advanced regulations, allowing the transformation of wastewater into potable water to combat climate-induced droughts [32]. Similarly, the European Union has implemented the Water Reuse Regulation, setting harmonised minimum water quality requirements to safely reuse treated urban wastewater in agricultural irrigation [33].

Despite these advancements, several barriers hinder the adoption of Membrane Bioreactor (MBR) technology in low-resource settings. High capital and operational costs, as well as the need for skilled personnel for operation and maintenance, pose significant challenges [34]. Additionally, the lack of economic incentives and supportive policies impedes the implementation of MBR systems in developing countries.

Future innovations in MBR technology are geared towards enhancing efficiency and reducing costs. Integrating artificial intelligence (AI) and machine learning algorithms offers promising avenues for optimising MBR operations, including predictive maintenance and real-time process control [14]. Hybrid systems combining MBRs with other treatment technologies, such as anaerobic digestion, are also being explored to improve energy recovery and reduce sludge production.

CONCLUSIONS

Membrane Bioreactor technology presents a viable and sustainable solution for urban wastewater treatment, offering superior effluent quality, reduced footprint, and potential for water reuse. Advancements in membrane materials, fouling mitigation strategies, and energy efficiency have significantly enhanced MBR performance. However, challenges related to high costs and operational complexities remain, particularly in low-resource settings. To facilitate the widespread adoption of MBR systems, it is imperative to develop supportive policies and economic incentives that encourage investment in this technology. Capacity-building initiatives that train personnel in the operation and maintenance of MBR systems are also crucial. Furthermore, continued research into hybrid systems and AI-driven optimisation can lead to more cost-effective and efficient MBR operations.

MBR technology holds significant promise for sustainable urban wastewater management. Strategic investments in research, policy development, and capacity building can unlock the full potential of MBR systems, contributing to environmental protection, resource recovery, and the realisation of circular economy goals in urban settings.

REFERENCES

1. Bakare-Abidola, T., Russell, W. J. A., Jorgensen, K., & Pérez, R. L. (2024). Enhanced extraction of methylene blue by dodecyl-methyl imidazolium dodecyl sulfate GUMBOS - magnetic alginate beads. *Chemosphere*, 370, 143991. doi: [10.1016/j.chemosphere.2024.143991](https://doi.org/10.1016/j.chemosphere.2024.143991)
2. Aborode, A. T., Adesola, R. O., Idris, I., Adio, W. S., Olapade, S., Oluwafisayo, G., Onifade, I. A., Fakorede, S., Bakare-Abidola, T., Olaoye, J., Ogunyemi, A. D., Ogundijo, O. A., Banwo, O. G., Bakre, A. A., Oladoye, P., Adegoye, G., & Jinadu, N. A. (2025). Challenges associated with PFAS detection method in Africa. *Environmental Health Insights*, 19. doi: [10.1177/11786302241310430](https://doi.org/10.1177/11786302241310430)
3. Al-Asheh, S., Bagheri, M., & Aidan, A. (2021). Membrane bioreactor for wastewater treatment: A review. *Case Studies in Chemical and Environmental Engineering*, 4, 100109. doi: [10.1016/j.cscee.2021.100109](https://doi.org/10.1016/j.cscee.2021.100109)
4. Abidola, T. B., Olaoye, J., Lawan, A. B., Oladeinde, J. O., & Tobi, A. S. (2025). Development of Sustainable Water Treatment Technologies for Communities Using Low-Cost Adsorbents. *International Journal of Scientific Research and Modern Technology*, 4(3), 36–42. doi: [10.38124/ijsrmt.v4i3.373](https://doi.org/10.38124/ijsrmt.v4i3.373)
5. Kanafin, Y. N., Kanafina, D., Malamis, S., Katsou, E., Inglezakis, V. J., Pouloupoulos, S. G., & Arkhangelsky, E. (2021). Anaerobic Membrane Bioreactors for Municipal Wastewater Treatment: A Literature review. *Membranes*, 11(12), 967. doi: [10.3390/membranes11120967](https://doi.org/10.3390/membranes11120967)
6. Shehata, N., Egirani, D., Olabi, A., Inayat, A., Abdelkareem, M. A., Chae, K., & Sayed, E. T. (2023). Membrane-based water and wastewater treatment technologies: Issues, current trends,

- challenges, and role in achieving sustainable development goals, and circular economy. *Chemosphere*, 320, 137993. doi: [10.1016/j.chemosphere.2023.137993](https://doi.org/10.1016/j.chemosphere.2023.137993)
7. Mahmood, Z., Cheng, H., & Tian, M. (2022). A critical review on advanced anaerobic membrane bioreactors (AnMBRs) for wastewater treatment: advanced membrane materials and energy demand. *Environmental Science Water Research & Technology*, 8(10), 2126–2144. doi: [10.1039/d2ew00300g](https://doi.org/10.1039/d2ew00300g)
8. Li, Y., Ren, Y., Ji, J., Li, Y., & Kobayashi, T. (2023). Anaerobic membrane bioreactors for municipal wastewater treatment, sewage sludge digestion and biogas upgrading: A review. *Sustainability*, 15(20), 15129. doi: [10.3390/su152015129](https://doi.org/10.3390/su152015129)
9. Hai, F. I., Yamamoto, K., Lee, C., Hai, F. I., Yamamoto, K., Lee, C., Jegatheesan, V., Visvanathan, C., Brepols, C., Chae, S., Ahn, Y., Hwang, Y., Jang, D., Meng, F., Shi, J., Lee, S., Shin, H., Asif, M. B., Hai, F. I., & Hai, F. I. (2019). Membrane biological reactors. In *IWA Publishing eBooks*. doi: [10.2166/9781780409177](https://doi.org/10.2166/9781780409177)
10. Judd, S. J. (2010). *The MBR Book: Principles and Applications of Membrane Bioreactors for Water and Wastewater Treatment*. Elsevier,
11. Yang, W., Cicek, N., & Ilg, J. (2005). State-of-the-art of membrane bioreactors: Worldwide research and commercial applications in North America. *Journal of Membrane Science*, 270(1–2), 201–211. doi: [10.1016/j.memsci.2005.07.010](https://doi.org/10.1016/j.memsci.2005.07.010)
12. Galinha, C. F., Sanches, S., & Crespo, J. G. (2018). Membrane bioreactors. In P. Luis, *Fundamental Modelling of Membrane Systems* (pp. 209–249). Elsevier.
13. Gkotsis, P., Banti, D., Peleka, E., Zouboulis, A., & Samaras, P. (2014). Fouling Issues in Membrane Bioreactors (MBRs) for wastewater treatment: Major mechanisms, Prevention and Control Strategies. *Processes*, 2(4), 795–866. doi: [10.3390/pr2040795](https://doi.org/10.3390/pr2040795)
14. Frontistis, Z., Lykogiannis, G., & Sarmpanis, A. (2023). Machine Learning Implementation in Membrane Bioreactor Systems: Progress, Challenges, and Future Perspectives: A review. *Environments*, 10(7), 127. doi: [10.3390/environments10070127](https://doi.org/10.3390/environments10070127)
15. Ashfaq, M. Y., Al-Ghouti, M. A., & Zouari, N. (2020). Functionalisation of reverse osmosis membrane with graphene oxide to reduce both membrane scaling and biofouling. *Carbon*, 166, 374–387. doi: [10.1016/j.carbon.2020.05.017](https://doi.org/10.1016/j.carbon.2020.05.017)
16. Wu, L., Gao, J., Zhao, W., Xu, X., Yin, Y., & Wu, L. (2016). Quality assessment of rainwater and harvested rainwater stored in different types of cisterns. *Water Science & Technology Water Supply*, 17(3), 652–664. doi: [10.2166/ws.2016.144](https://doi.org/10.2166/ws.2016.144)
17. Meng, F., Zhang, H., Yang, F., & Liu, L. (2007). Characterisation of cake layer in submerged membrane bioreactor. *Environmental Science & Technology*, 41(11), 4065–4070. doi: [10.1021/es062208b](https://doi.org/10.1021/es062208b)
18. Le-Clech, P. (2010). Membrane bioreactors and their uses in wastewater treatments. *Applied Microbiology and Biotechnology*, 88(6), 1253–1260. doi: [10.1007/s00253-010-2885-8](https://doi.org/10.1007/s00253-010-2885-8)
19. Köse-Mutlu, B., Ergön-Can, T., Koyuncu, I., & Lee, C. (2019). Quorum quenching for effective control of biofouling in membrane bioreactor: A comprehensive review of approaches, applications, and challenges. *Environmental Engineering Research*, 24(4), 543–558. doi: [10.4491/eer.2018.380](https://doi.org/10.4491/eer.2018.380)
20. Liu, C., Zhang, He, Y., Zhao, X., & Bai, R. (2009). Modification of membrane surface for anti-biofouling performance: Effect of anti-adhesion and anti-bacteria approaches. *Journal of Membrane Science*, 346(1), 121–130. doi: [10.1016/j.memsci.2009.09.028](https://doi.org/10.1016/j.memsci.2009.09.028)
21. Yeon, K., Cheong, W., Oh, H., Lee, W., Hwang, B., Lee, C., Beyenal, H., & Lewandowski, Z. (2008). Quorum sensing: A new biofouling control paradigm in a membrane bioreactor for advanced wastewater treatment. *Environmental Science & Technology*, 43(2), 380–385. doi: [10.1021/es8019275](https://doi.org/10.1021/es8019275)

22. Giwa, A., Dufour, V., Marzooqi, F. A., Kaabi, M. A., & Hasan, S. (2016). Brine management methods: Recent innovations and current status. *Desalination*, 407, 1–23. doi: [10.1016/j.desal.2016.12.008](https://doi.org/10.1016/j.desal.2016.12.008)
23. Trussell, R. S., Merlo, R. P., Hermanowicz, S. W., & Jenkins, D. (2006). The effect of organic loading on process performance and membrane fouling in a submerged membrane bioreactor treating municipal wastewater. *Water Research*, 40(14), 2675–2683. doi: [10.1016/j.watres.2006.04.020](https://doi.org/10.1016/j.watres.2006.04.020)
24. Smith, A. L., Stadler, L. B., Love, N. G., Skerlos, S. J., & Raskin, L. (2012). Perspectives on anaerobic membrane bioreactor treatment of domestic wastewater: A critical review. *Bioresource Technology*, 122, 149–159. doi: [10.1016/j.biortech.2012.04.055](https://doi.org/10.1016/j.biortech.2012.04.055)
25. Garrido-Baserba, M., Sedlak, D. L., Molinos-Senante, M., Barnosell, I., Schraa, O., Rosso, D., Verdaguer, M., & Poch, M. (2024). Using water and wastewater decentralisation to enhance the resilience and sustainability of cities. *Nature Water*. doi: [10.1038/s44221-024-00303-9](https://doi.org/10.1038/s44221-024-00303-9)
26. WaterWorld. (2010). Retrofitting Existing MBR Systems with Next-Generation MBR Technology. Retrieved from <https://www.waterworld.com/wastewater-treatment/article/16220987/retrofitting-existing-mbr-systems-with-next-generation-mbr-technology>
27. Huang, Y., Jeffrey, P., & Pidou, M. (2023). Municipal wastewater treatment with anaerobic membrane Bioreactors for non-potable reuse: A review. *Critical Reviews in Environmental Science and Technology*, 54(10), 817–839. doi: [10.1080/10643389.2023.2279886](https://doi.org/10.1080/10643389.2023.2279886)
28. Livingston, D., & Judd, S. (2024). MBR Technology Problems and Solutions: Report from The MBR Clinic. Retrieved from <https://www.thembrsite.com/features/mbr-technology-problems-and-solutions-mbr-clinic>
29. Dalri-Cecato, L., Battistelli, A. A., & Lapolli, F. R. (2020). CAPEX and OPEX evaluation of a membrane bioreactor aiming at water reuse. In *Climate change management* (pp. 137–152). doi: [10.1007/978-3-030-57235-8_12](https://doi.org/10.1007/978-3-030-57235-8_12)
30. Banti, D. C., Tsangas, M., Samaras, P., & Zorpas, A. (2020). LCA of a membrane bioreactor compared to activated sludge system for municipal wastewater treatment. *Membranes*, 10(12), 421. doi: [10.3390/membranes10120421](https://doi.org/10.3390/membranes10120421)
31. EPA. (2024). *Guidelines for Water Reuse*. Retrieved from <https://www.epa.gov/sites/default/files/2019-08/documents/2012-guidelines-water-reuse.pdf>
32. Habeshian, S. (2023). *From sewage to sip: California adopts new water reuse rules*. Retrieved from <https://www.axios.com/2023/12/22/california-sewage-drinking-water-reuse>
33. European Commission. (2023). *Water reuse: New EU rules to improve access to safe irrigation*. Retrieved from https://environment.ec.europa.eu/news/water-reuse-new-eu-rules-improve-access-safe-irrigation-2023-06-26_en
34. Jijingi, H. E., Yazdi, S. K., Abakar, Y. A., & Etim, E. (2024). Evaluation of membrane bioreactor (MBR) technology for industrial wastewater treatment and its application in developing countries: A review. *Case Studies in Chemical and Environmental Engineering*, 10, 100886. doi: [10.1016/j.cscee.2024.100886](https://doi.org/10.1016/j.cscee.2024.100886)