OPEN ACCESS Freely available online

ISSN: 2155-9589
Journal of Membrane Science & Technology

Perspective

Membrane Bioreactors in Advanced Wastewater Treatment Systems

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DESCRIPTION

Membrane bioreactors have become widely used in modern wastewater treatment because they combine biological treatment with membrane filtration in a single operational system. This technology supports effective removal of suspended solids, organic pollutants, microorganisms and nutrients from municipal and industrial wastewater. Increasing urban population, industrial expansion and stricter environmental regulations have encouraged treatment facilities to adopt advanced purification methods capable of producing high-quality treated water suitable for discharge or reuse. Membrane bioreactor systems provide compact operation, stable treatment performance and reduced land requirements compared with many conventional treatment methods.

A membrane bioreactor integrates biological degradation processes with membrane separation units. Microorganisms present in the bioreactor consume organic contaminants and convert them into simpler compounds such as carbon dioxide, water and biomass. The membrane filtration unit then separates treated water from suspended solids and microbial flocs. This combination eliminates the need for secondary clarifiers commonly used in conventional activated sludge systems. Membrane modules may be submerged directly inside the biological reactor or installed externally with separate circulation loops depending on system design.

Microfiltration and ultrafiltration membranes are commonly used in membrane bioreactor systems. These membranes retain bacteria, suspended solids and many pathogens while allowing treated water to pass through. The resulting effluent quality is generally higher than that produced by traditional wastewater treatment facilities. Low turbidity and reduced microbial concentration make membrane bioreactor effluent suitable for non-potable reuse applications such as irrigation, industrial cooling and process water supply. Municipal wastewater treatment plants have adopted membrane bioreactor systems because of their ability to operate efficiently within limited space. Conventional activated sludge systems often require large settling tanks and extensive infrastructure. Membrane bioreactors reduce facility size by replacing gravity-based clarification with direct membrane filtration. High biomass concentrations can also be maintained within the reactor, increasing biological treatment capacity and improving organic pollutant removal rates.

Industrial sectors including pharmaceuticals, food processing, textiles, petrochemicals and chemical manufacturing use membrane bioreactors for treatment of complex wastewater streams. Industrial discharge frequently contains high concentrations of organic matter, oils, surfactants, dyes and toxic compounds that may be difficult to remove using traditional methods alone. Membrane bioreactors provide stable biological treatment while preventing biomass washout through membrane retention. This allows microorganisms additional time to degrade pollutants effectively.

Food processing industries use membrane bioreactors to treat wastewater generated during dairy production, beverage manufacturing and meat processing operations. Waste streams from these facilities often contain proteins, fats, carbohydrates and suspended solids that contribute to elevated biochemical oxygen demand. Biological degradation combined with membrane separation reduces pollutant levels significantly while allowing water recovery for secondary applications within processing facilities.

Textile manufacturing facilities also benefit from membrane bioreactor technology because textile wastewater may contain dyes, detergents and organic additives resistant to simple treatment methods. Biological processes remove biodegradable compounds, while membrane filtration retains suspended solids and microorganisms. Additional polishing stages such as reverse osmosis may further improve water quality for industrial reuse. One of the primary operational challenges associated with membrane bioreactors is membrane fouling.

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Received: 16-Feb-2026, Manuscript No. JMST-26-31633; **Editor assigned:** 18-Feb-2026, Pre QC No. JMST-26-31633 (PQ); **Reviewed:** 04-Mar-2026, QC No. JMST-26-31633; **Revised:** 11-Mar-2026, Manuscript No. JMST-26-31633 (R); **Published:** 18-Mar-2026, DOI: 10.35248/2155-9589.26.16.452

Citation: Volkov E (2026). Membrane Bioreactors in Advanced Wastewater Treatment Systems. J Membr Sci Technol. 16:452.

CONCLUSION

Water scarcity and increasing environmental protection requirements continue to encourage wider implementation of membrane bioreactor systems worldwide. Their ability to produce high-quality treated water with compact infrastructure makes them suitable for densely populated urban regions and industrial facilities seeking water reuse opportunities. Continued progress in membrane materials, energy management and automated process control is expected to support more efficient and sustainable wastewater treatment operations in the future.