Membrane Bioreactors for Wastewater Treatment

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Module 1: Executive Summary

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** the feasibility and operational advantages of MBR technology compared to conventional wastewater treatment.
- **Identify** the impact of integrating MBR systems with Reverse Osmosis (RO) for salinity reduction and water reclamation.
- **Compare** the capital and operational costs associated with MBR systems treating raw wastewater versus advanced primary effluent.

Executive Summary: Membrane Bioreactor (MBR) technology is a proven, efficient method for producing high-quality reclaimed water, offering a reduced footprint and superior effluent compared to conventional methods. Pilot testing demonstrates that MBR systems from leading manufacturers can successfully treat both raw wastewater and advanced primary effluent containing chemical residuals while providing a suitable feed for reverse osmosis. Utilizing advanced primary effluent as a source water can significantly reduce reclamation costs.

MBR Technology Fundamentals

Wastewater reclamation is a critical global strategy for conserving natural drinking water resources. The **Membrane Bioreactor (MBR)** process combines conventional activated sludge treatment with low-pressure membrane filtration, typically utilizing **Microfiltration (MF)** or **Ultrafiltration (UF)**.

Key Advantages of MBR Systems

- **Elimination of Clarifiers:** The membrane component serves the solid-liquid separation function, removing the need for secondary clarification.
- **Reduced Footprint:** MBR systems require significantly less space than conventional activated sludge (CAS) plants.
- **Superior Water Quality:** MBRs produce consistent effluent that is highly effective for downstream applications.
- **Ease of Operation:** The technology simplifies the overall treatment process.

Advanced Treatment and Salinity Reduction

For irrigation and industrial applications, it is often necessary to reduce the inherent salinity of reclaimed water. Because MBR effluent is of such high quality, it serves as an ideal feed for **Reverse Osmosis (RO)** membranes, which act as a final polishing step for salt removal.

Pilot Study Objectives and Methodology

Beginning in 2001, the City of San Diego and Montgomery Watson Harza (MWH) partnered with the Bureau of Reclamation to optimize MBR operation and encourage industry competition. The study performed a parallel evaluation of four leading suppliers:

- US Filter Corporation/Jet Tech Products Group
- Zenon Environmental, Inc.
- Ionics/Mitsubishi Rayon Corporation
- Enviroquip Inc./Kubota Corporation

Testing Phases

- **Phase I:** Evaluated Kubota and US Filter systems on **raw wastewater** (3,500+ hours) and **advanced primary effluent** (1,200+ hours).
- **Phase II:** Evaluated Zenon and Mitsubishi systems on **advanced primary effluent** for over 4,000 hours.
- **RO Integration:** Kubota MBR effluent was treated with RO membranes at 50% recovery during the pilot, though projections suggest full-scale recovery rates of **75% to 90%** are achievable.

Operational Performance and Optimization

Optimization focused on performance across different wastewater types, flux rates, and **Hydraulic Retention Times (HRT)**.

Performance Milestones

- **Chemical Resilience:** Systems operated on advanced primary effluent containing coagulant and polymer residuals with minimal fouling.
- **Contaminant Removal:** All systems consistently achieved:
  - **BOD:** < 2 mg/L
  - **Turbidity:** < 0.1 NTU
  - **Microbial:** Up to 6-log removal of total and fecal coliform
- **Nitrification:** Influent ammonia (averaging 30 mg/L) was reduced to **< 1 mg/L**.
- **Flux and HRT:** Testing confirmed the feasibility of operating at flux rates exceeding **20 gfd** and HRTs as low as **2 hours**.

💡 **Design Tip:** While not a primary goal of the study, denitrification was successfully achieved in the Kubota system through the inclusion of a dedicated anoxic zone.

Economic Evaluation of Full-Scale Systems

Cost estimates were developed for facilities ranging from **0.2 to 10 MGD**, covering capital expenses, membrane costs from suppliers, and preliminary design calculations for biological processes and disinfection.

Cost Comparison (1-MGD Systems)

- **Raw Wastewater Feed:** $1.81 - $2.23 per 1,000 gallons
- **Advanced Primary Effluent Feed:** $1.57 - $2.00 per 1,000 gallons

⚠️ **Safety Constraint:** Proper salinity reduction through RO must be ensured if the reclaimed water is intended for specific industrial uses or sensitive irrigation to prevent equipment damage or soil degradation.

Checkpoint Quiz

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1. **Which component of the conventional wastewater treatment process is eliminated by the use of MBR technology?**
   a) Aeration tanks
   b) Secondary clarifiers
   c) Headworks
   d) Disinfection chambers

Answer: (b). The membrane component in an MBR system performs the solid-liquid separation, making conventional clarifiers unnecessary.

2. **According to the pilot study, what is the projected recovery range for RO membranes operating on MBR effluent in a full-scale application?**
   a) 25% to 40%
   b) 50% to 60%
   c) 75% to 90%
   d) 95% to 100%

Answer: (c). While the pilot unit operated at 50% recovery, results indicated that MBR effluent is high enough quality to support recovery rates typical of brackish groundwater (75-90%).

3. **What was the observed impact of using advanced primary effluent as a feed source for MBR systems?**
    a) It caused severe and immediate membrane fouling.
    b) It prevented the systems from achieving nitrification.
    c) It allowed for successful operation with little fouling and reduced overall costs.
    d) It required increasing the HRT to over 10 hours.

Answer: (c). The study found that MBR systems could handle coagulant and polymer residuals in advanced primary effluent and that this feed source lowered the estimated cost per 1,000 gallons.

Module 2: Introduction

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** the critical design parameters (SRT, HRT, and flux) that influence the footprint and cost of full-scale MBR systems.
- **Assess** the advantages and potential risks of utilizing advanced primary effluent as a feed source for MBR processes.
- **Analyze** the efficacy of MBR technology as a pretreatment method for Reverse Osmosis (RO) in high-salinity water reclamation.

Executive Summary: Rapid population growth and diminishing water supplies have accelerated the adoption of Membrane Bioreactor (MBR) technology for global water reclamation. While MBR systems offer superior effluent quality and smaller footprints, industry growth necessitates the qualification of new suppliers, optimization of operating parameters like HRT and flux, and the refinement of cost estimates. This study evaluates new manufacturers in the US market and explores the integration of MBR with advanced primary treatment and Reverse Osmosis to provide a comprehensive roadmap for full-scale municipal implementation.

Design Fundamentals

Wastewater reclamation is increasingly necessary to conserve natural drinking water resources. MBR technology is at the leading edge of this transition due to significant technological advances and declining implementation costs.

Market Landscape and Innovation

While Zenon and Mitsubishi were the primary established manufacturers in the US at the start of this study, new suppliers have introduced unique design innovations:

- **Flat Sheet Membranes:** Utilized by Kubota for solid-liquid separation rather than traditional hollow fibers.
- **Jet Aeration:** Utilized by US Filter/Jet Tech to mitigate membrane fouling.

Expanding the selection pool of manufacturers allows engineers to better meet specific site requirements and limitations.

Operating Parameter Optimization

Key parameters affecting system footprint and cost include **Sludge Retention Time (SRT)**, **Hydraulic Retention Time (HRT)**, and **Membrane Flux**. Traditional values are being challenged by more optimal pilot-scale results: