Evaluation of multi-stage Osmotically Assisted Reverse Osmosis configurations for high-salinity wastewater treatment

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Osmotically Assisted Reverse Osmosis (OARO) is an emerging membrane-based technology designed to overcome the limitations of conventional reverse osmosis in the treatment of hypersaline wastewater. By introducing a sweep solution on the permeate side, OARO reduces the effective osmotic pressure gradient, enabling higher driving forces and improved water recovery from saline streams. This study presents a comprehensive evaluation of OARO performance through both experimental investigation and process simulation.

A pilot-scale OARO unit was developed and commissioned using a prototype spiral-wound membrane designed to withstand up to 30 bar and to minimise mechanical deformations such as telescoping. Experimental tests were carried out using sodium chloride solutions with concentrations ranging from 1M to 4M (approximately 58–234 g/L), under operating pressures between 20 and 28 bar. The collected data were used to calibrate and validate a mathematical model describing transport phenomena and hydraulic behaviour in the OARO system, including concentration polarization, pressure drop, and sweep-side flow dynamics.

The validated model was implemented in a commercial process simulation software to investigate the performance of multi-stage OARO configurations designed for high-recovery operation. The simulations were carried out in the context of a case study related to the treatment of wastewater from the textile industry, a sector known for high-salinity effluents. Simulated layouts were benchmarked against Ultra-High Pressure Reverse Osmosis (UHPRO), focusing on specific energy consumption, achievable concentrations, and overall process efficiency. Results show that while UHPRO remains the most energy-efficient solution for concentrating brine streams up to 100 g/L of total dissolved solids, OARO offers significant advantages for reaching higher concentrations, effectively extending the applicability of membrane-based separation beyond the current UHPRO limits.

This research contributes to the broader chemical engineering challenge of developing scalable, energy-efficient solutions for industrial water reuse and brine minimization. The findings underline the potential of OARO as a complementary technology to UHPRO, particularly in Zero Liquid Discharge (ZLD) systems, providing a viable approach for handling high-salinity wastewater where traditional methods fall short. The combined experimental and simulation-based approach offers valuable insight into the design and optimization of hybrid membrane processes for high-salinity wastewater treatment.

Keywords: *Osmotically Assisted Reverse Osmosis (OARO), High-salinity water treatment, Membrane Technologies, Process Simulation*