

OVERVIEW OF NAWI OBJECTIVES

1. Develop a better understanding of the factors affecting EMF efficiency for membrane scaling control under different operating conditions and water chemistries.
2. Develop real-time monitoring, advanced characterization, and numerical simulation to elucidate the impact of EMF on water solutions, nucleation, crystallization, and precipitation in bulk solution and on membrane surface.
3. Perform a techno-economic analysis (TEA) and life cycle assessment (LCA) of EMF treatment in comparison with chemical pretreatment methods.
4. Issue guidance on how EMF can be applied for scaling control in water treatment processes and systems

RESEARCH BRIEF
Start Date: Apr 1, 2022 | Duration: 24 months

NAWI
National Alliance
For Water Innovation

Electromagnetic Field for Membrane Scaling Control

Pei Xu | New Mexico State University
pxu@nmsu.edu

Challenge
Membrane scaling is a major impediment to the successful implementation of desalination technologies. The current state-of-the-art for scaling prevention is pH adjustment and dosing of anti-scalants, which are proprietary chemicals that allow sparingly soluble compounds, such as silica and calcium sulfate, to remain soluble even when supersaturated, which prevents them from precipitating on membrane surfaces. Unfortunately, anti-scalants are expensive consumables and need to be replenished, contribute to the waste stream, and are only effective to a certain point: operating above this threshold can still result in membrane scaling.

Research Approach
This project will focus on modeling, bench-scale experiments, and developing a suite of real-time, advanced characterization methods to elucidate the mechanisms and limitations of EMF for membrane scaling control. The main research objectives include:

1. Developing a better understanding of the factors affecting EMF efficiency for membrane scaling control under different operating conditions and water chemistries with generic and representative commercial EMF technologies.
2. Developing real-time monitoring, advanced characterization, and numerical simulation to elucidate the impact of EMF on water solutions, nucleation, crystallization, and precipitation in bulk solution and on membrane surface.
3. Performing a techno-economic analysis (TEA) and life cycle assessment (LCA) of EMF treatment in comparison with chemical pretreatment methods.
4. Issuing guidance on how EMF can be applied for scaling control in water treatment processes and systems.

Impact
Successful completion of this project will lead to an improved understanding of how EMF properties impact nucleation, crystallization, and precipitation of constituents in water at the atomic-, micro- and macro-scale. This new knowledge can serve as the basis for the development of next-generation technologies that can displace traditional anti-scalants help enable pipe parity by reducing or eliminating the cost of exogenous chemicals, their handling, and onsite storage.

RESEARCH PARTNERS
New Mexico State University; Fungui Shu; Huiyao Wang; Lambis Papadou; Pei Xu; Yanfeng Wang; Oak Ridge National Laboratory; Ke Yuan; Lawrence Anovitz.

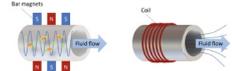


Figure 1. Illustration of EMF devices.

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ENERGY

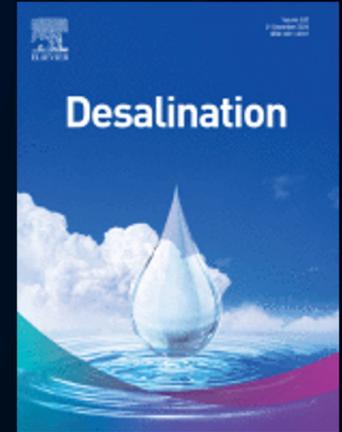
PAPER #1:

Numerical modeling of electromagnetic field spatiotemporal evolution to evaluate the effects on calcium carbonate crystallization

Objective: Quantify actual electric and magnetic field strengths delivered to bulk solution by three different AC-induced EMF devices (two indirect ferrite-coils, one Flow-Tech direct-antenna) and determine which field component drives CaCO_3 crystallization changes.

Setup: Synthetic CaCO_3 supersaturated solution circulated through 316 SS pipe. ($\text{SI}_{\text{calcite}} \approx 1.3\text{--}1.5$, Aragonite $\text{SI} \approx 1.15\text{--}1.35$, initial conductivity $\approx 2.8\text{--}3.0$ mS/cm.)

Method: High-fidelity 3-D COMSOL Multiphysics models validated against oscilloscope and 3-D Hall probe measurements; static and circulating precipitation experiments monitored by conductivity, SEM, XRD, and particle-size analysis.



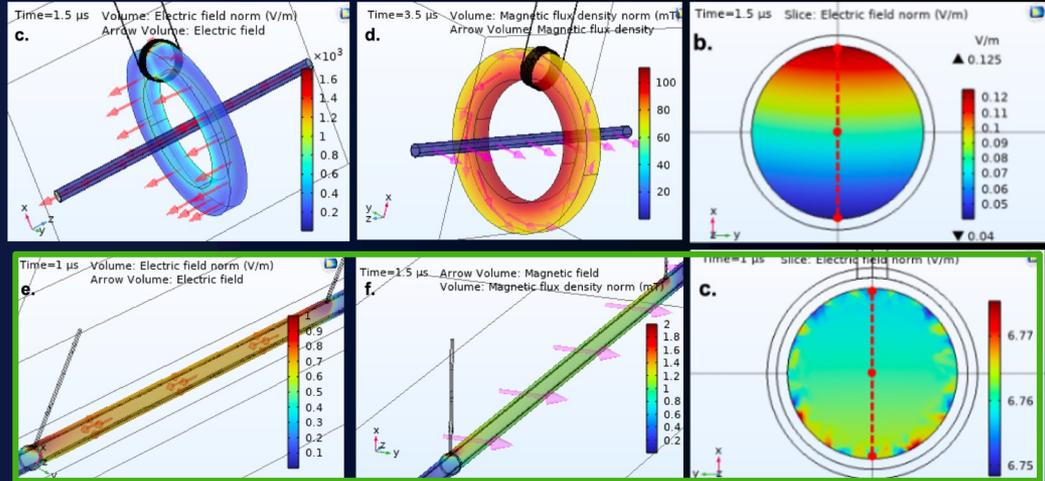
TAKEAWAY #1

DESALINATION (DEC. 2024)

Direct-EMF is the only available technology that delivers a relevant electrical field into the bulk water.

- Indirect systems lose >99% of their electrical field to skin-effect shield of metallic piping

*"The antenna direct inductor [Flow-Tech] significantly accelerated the CaCO_3 crystallization processes compared to the indirect inductors... **The Lorentz force created by the electric field** rather than the magnetic field, serves as the primary driving force for ion interactions and precipitation processes in CaCO_3 aqueous solutions..."*



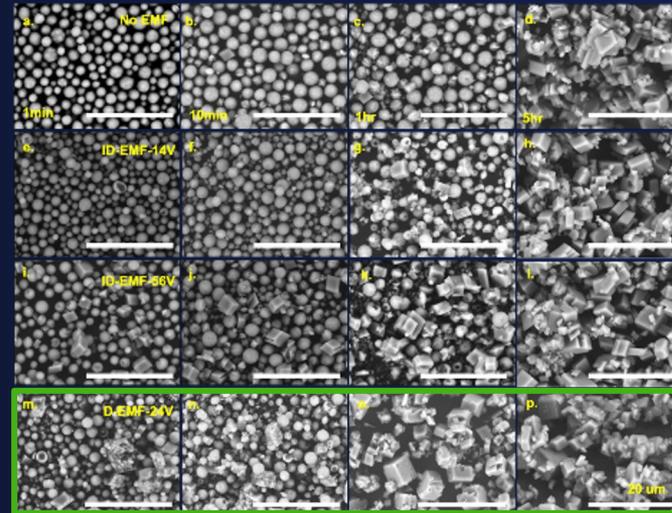
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TAKEAWAY #2

DESALINATION (DEC. 2024)

Direct-EMF significantly accelerates the crystallization rate and total volume of CaCO_3 precipitates compared to the indirect inductors.

“After 1 hour, more calcite formed under [the indirect inductors]. All of the vaterite was converted into calcite under [Flow-Tech], while the precipitate was still primarily vaterite without an EMF... Thus, the stronger the electric field, the faster the crystallization rate of CaCO_3 in a supersaturated solution and the conversion to the stabler solid phase, suggesting the electric field provides the energy to overcome activation barriers, allowing precipitation and recrystallization to proceed faster.”



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PAPER #2:

Mechanisms of Electromagnetic Field Control on Mineral Scaling in Brackish Water Reverse Osmosis: Combined Homogeneous and Heterogeneous Nucleation

Objective: Determine how Flow-Tech Direct-EMF affects homogeneous vs heterogeneous CaCO_3 nucleation and scaling reversibility during RO treatment of near-saturated ($\text{SI} \approx 0$) real brackish groundwater and supersaturated synthetic CaCO_3 water.

Setup: Bench-scale cross-flow RO system with two flat-sheet cells in series; real brackish groundwater from BGNDRF (TDS 5,440–5,860 mg/L); Flow-Tech device installed upstream of membrane cells.

Method: Four consecutive 9-hour RO cycles followed by 5–15 min DI-water hydraulic flushing; permeate flux, conductivity, turbidity, SEM/EDX, and XRD used to compare scaling extent and cleanability with vs without EMF.



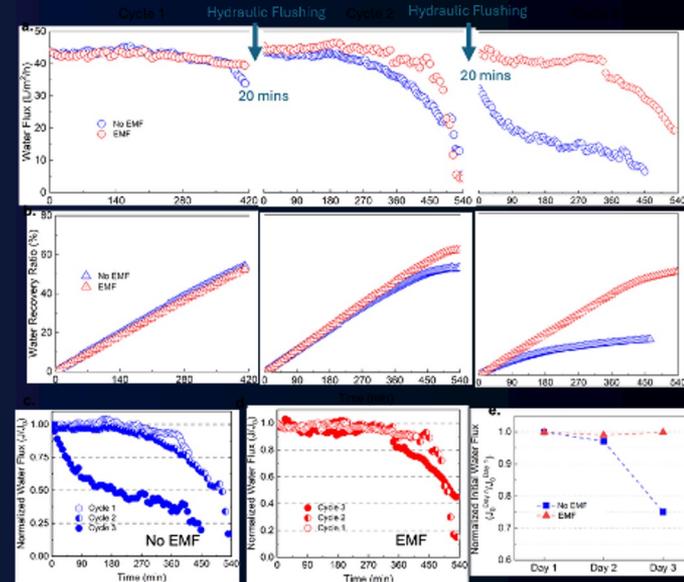
TAKEAWAY #1

SEPARATION & PURIFICATION TECHNOLOGY (MAR. 2025)

Flow-Tech + extended hydraulic flushing essentially eliminates irreversible CaCO_3 scaling in near-saturated brackish groundwater RO ($SI \approx 0$).

*"EMF exhibits greater efficacy in treating near-saturated water (SI_0), especially when coupled with extended hydraulic flushing...For example, **almost 100% initial flux recovery was achieved after a 20-minute HF cleaning**"*

*"In Cycles 2 and 3, [Flow-Tech] treatment significantly improved membrane permeability and water recovery. For example, [Flow-Tech] treatment resulted in...a water recovery of **51.3%**...whereas the control experiment exhibited...a water recovery of 17.6%"*



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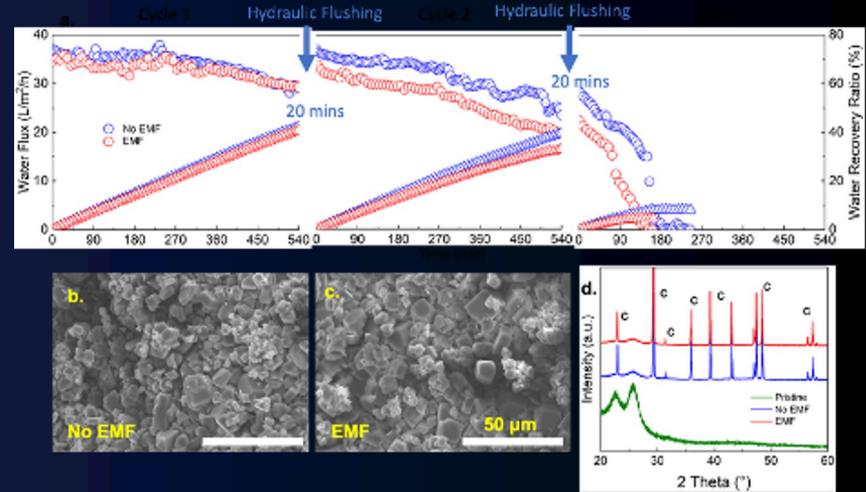
TAKEAWAY #2

SEPARATION & PURIFICATION TECHNOLOGY (MAR. 2025)

In highly supersaturated conditions, Flow-Tech can aggressively accelerate homogeneous precipitation and increase efficiency of prefiltration.

“For supersaturated CaCO_3 solutions, EMF promoted bulk calcite precipitation due to the magnetohydrodynamic effect (Figure 7), resulting in significant homogeneous precipitation of CaCO_3 that readily adheres to spacers and membranes, accelerating flux decline.”

*“Our findings also suggest that **EMF, combined with cartridge filtration, can reduce ion concentration in the feed solution** by promoting bulk precipitation within supersaturated solutions.”*



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PAPER #3:

Distinct Impacts of Electromagnetic Fields on Gypsum and Silica Scaling in Reverse Osmosis

Objective: Articulate the differing mechanisms and effectiveness of Flow-Tech's Direct-EMF on gypsum (crystallization-driven) vs silica (polymerization-driven) scaling in RO, including scaling reversibility with hydraulic flushing.

Setup: Same bench-scale RO system; two feeds: (1) gypsum-targeted synthetic brackish water ($SI_{\text{gypsum}} \approx -0.13$), (2) real RO concentrate from KBH plant containing 159 mg/L silica ($SI_{\text{silica}} \approx 0.14-0.3$).

Method: 3–4 RO cycles (9 hours each) + 15-min HF cleaning, plus extended 50-hour silica runs; permeate flux, flux recovery, turbidity, SEM/EDX, XRD, and XPS used to characterize scale morphology, composition, and cleanability with vs without Flow-Tech.

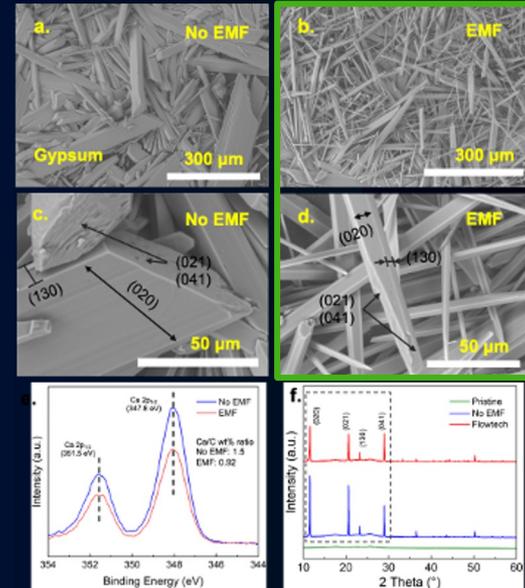


TAKEAWAY #1

Flow-Tech + HF is highly effective against gypsum scaling in undersaturated and saturated feeds.

“Scales formed under EMF treatment consisted of smaller, needle-like crystals that were less adherent. This morphological transformation suggests that EMF modifies gypsum crystallization, promoting the formation of less dense and more fragmented structures that are more easily removed through HF.”

GYPSUM AND SILICA (JUN. 2025)



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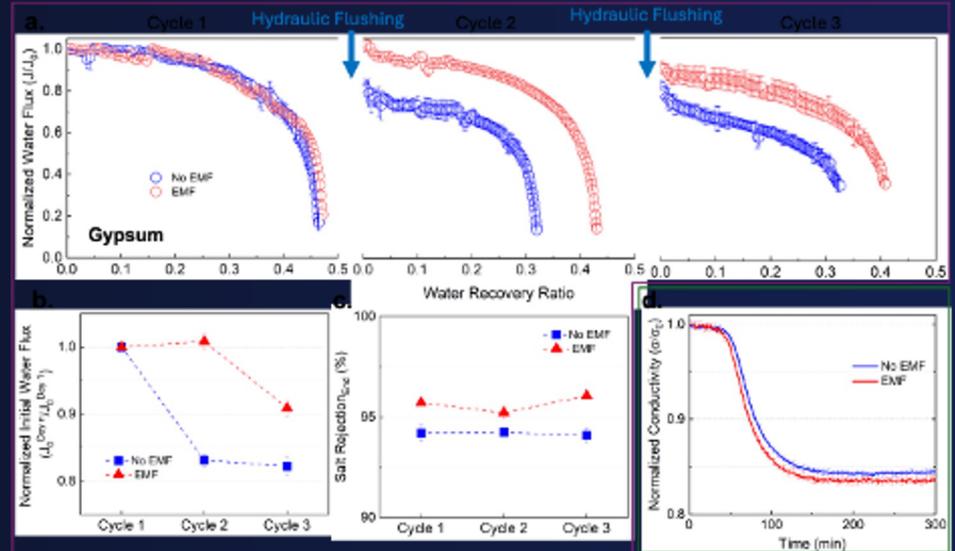
TAKEAWAY #2

GYPSUM AND SILICA (JUN. 2025)

Flow-Tech + hydraulic flushing reversed gypsum scaling, achieved initial flux recovery rates, and increased water recovery ratios.

- **Flow-Tech improved water recovery ratio by 11% (43% vs 32%) and 8% (41% vs 33%), respectively, in Cycles 2 and 3**
 - For context, pristine membranes achieved 47% water recovery ratio

“Under EMF treatment, the membrane achieved high initial flux recovery rates of 100% and 92% in Cycles 2 and 3, respectively, whereas the control group showed lower recovery rates of 83% and 82%.”



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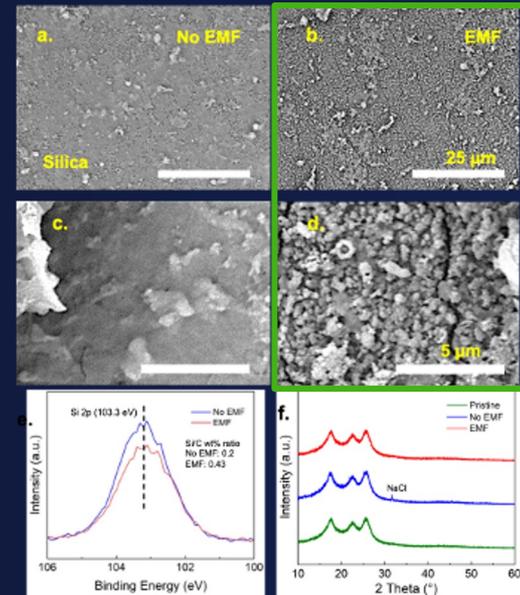
TAKEAWAY #2

Flow-Tech uniquely demonstrated mitigation of silica scaling, even in supersaturated concentrate

- Scales formed under Flow-Tech treatment become more granular and rough, disrupting typical structure of silica deposits
- Reduces resistance to water flow, enhancing membrane performance

“EMF demonstrates effectiveness in improving membrane permeability in both feed-and-bleed and recirculation modes of RO desalination compared to operations without EMF. This improvement is attributed to EMF-induced alterations in silica deposit morphology, resulting in more fragmented and less compact particle structures.”

GYPSUM AND SILICA (JUN. 2025)



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