Is closed-circuit reverse osmosis less prone to scaling than conventional plug flow operation?

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Open-Minded

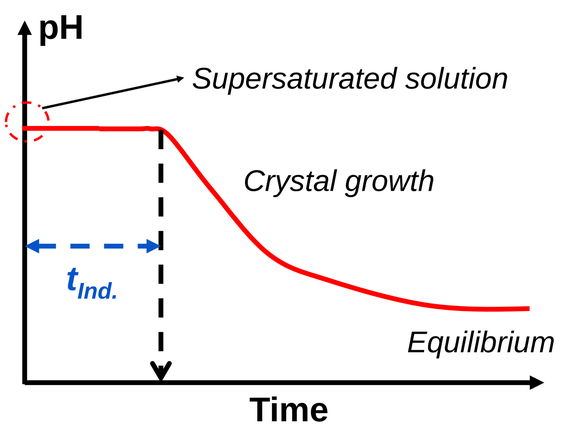
Background and Motivation

Membrane scaling, i.e., precipitation of sparingly soluble salts, e.g., **$CaCO_3$**, onto the membrane surface is a major bottleneck in inland desalination. Precipitation occurs when:

1. **Positive super-saturation index → SI > 0** ***(Thermodynamics)***

   where $SI = \log\left(\frac{IAP}{K_{SP}}\right)$

2. **Nucleation induction time** ($t_{Ind.}$) exceeded ***(Kinetics)***



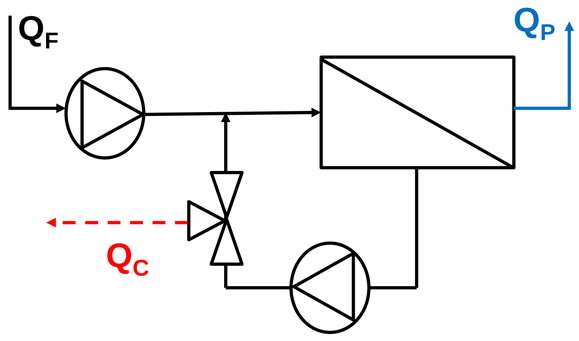
Research Questions:

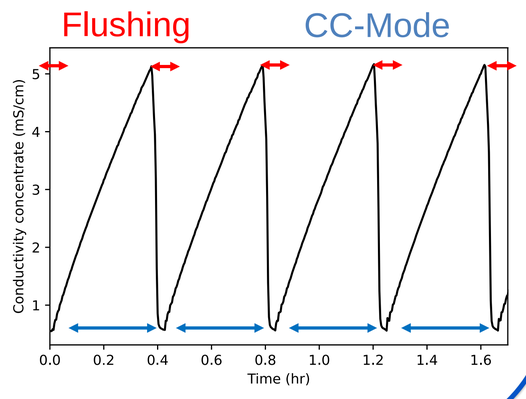
- ❑ Clear **induction time observed**?
- ❑ Possible to filtrate a highly super-saturated solution without AS dosage without scaling by **undershooting the nucleation induction time** ($t_{CC\text{-}Mode} < t_{Ind.}$)?
- ❑ CCRO less prone to scaling than conventional plug flow RO (PFRO)?

Antiscalants (AS) prevent scaling to enable economic recoveries, but the discharge of concentrates containing AS is disputed.

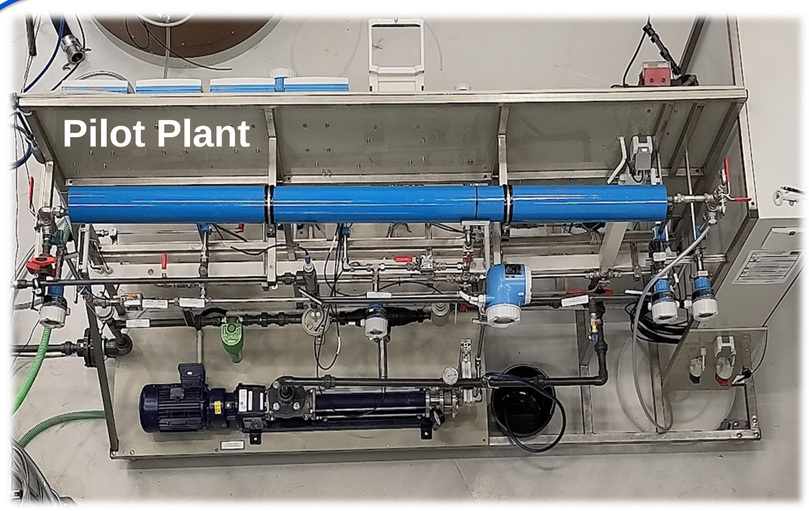
Discontinuous operation, e.g., **closed-circuit reverse osmosis (CCRO)** may allow high recovery operation without AS by **undershooting the nucleation induction time. CCRO** consist of two **alternating modes**:

1. **Closed-circuit mode**: Filtration mode where $Q_F = Q_P$
2. **Flushing**: Concentrate is flushed out with fresh feed solution, $Q_F >> Q_P$



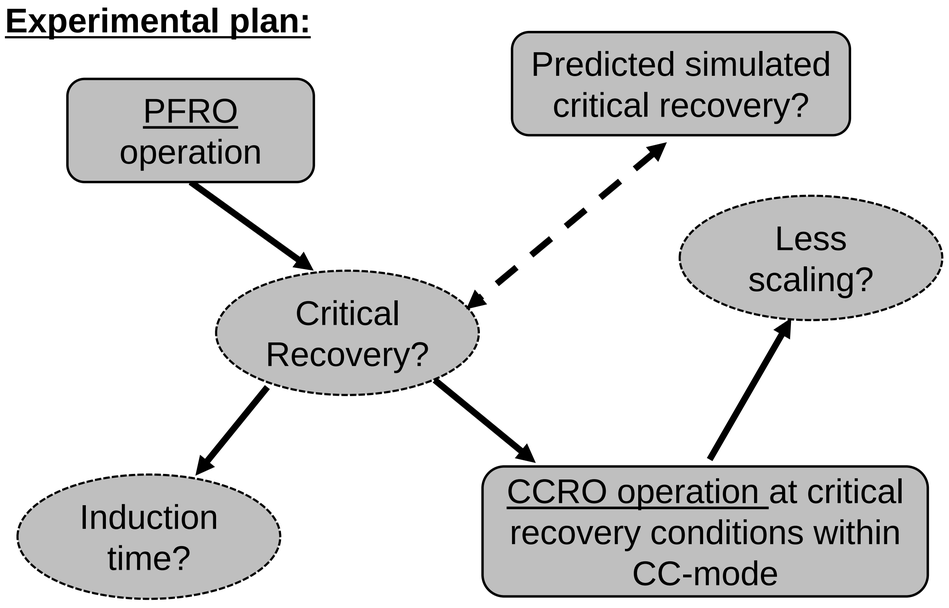


Material and Methods



- ❑ Fully automated RO-plant operated either as PFRO with internal concentrate recycling or as CCRO
- ❑ PV with **2 * 4'' Suez AK-85P** in series

Experimental plan:



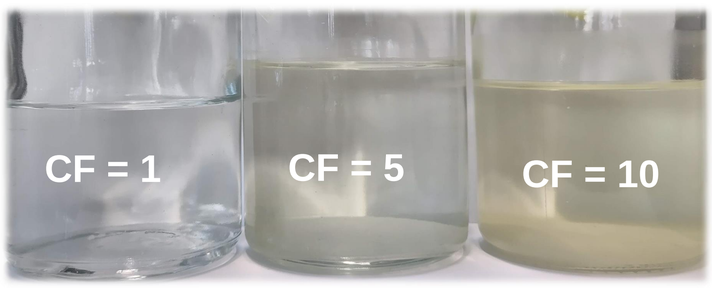
Tab.1: Feed August/September 2022

Parameter	Mean (n=8)	Sd
Temperature	20.9 °C	± 1.1 °C
pH	7.74	± 0.1
Conductivity	520 µS/cm	± 4 µS/cm
HCO_3^-	146 mg/L	± 4.2 mg/L
Ca^{2+}	96 mg/L	± 1.9 mg/L
Mg^{2+}	4.6 mg/L	± 0.1 mg/L
Na^+	22 mg/L	± 0.4 mg/L
SO_4^{2-}	54 mg/L	± 3.0 mg/L
Cl^-	38 mg/L	± 10.8 mg/L
NO_3^-	13 mg/L	± 0.6 mg/L
TDS	366 mg/L	± 10 mg/L
$SI_{Calcite}$	0.33	

Results

PFRO-operation

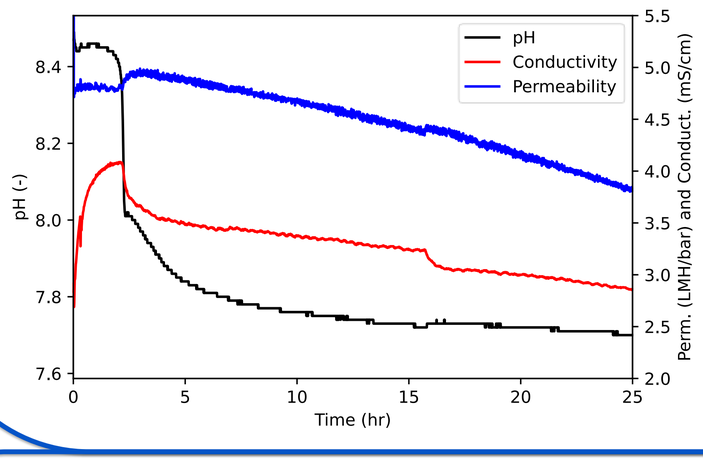
- ❑ **No scaling at 80%** recovery (20 LMH) and **85%** recovery (30 LMH) **for more than 7 and 2 days**, respectively
- ❑ **$CaCO_3$-Scaling at 90% recovery (critical recovery) at 20 LMH** and **$SI_{Calcite}$ = 2.3** after 2 hours (**$t_{Ind.}$ = 2 hr**), with:
  - ✓ Dropping concentrate pH, conductivity & $c_{Ca,C}$
  - ✓ Decreasing permeability & retention
  - ✓ Increasing turbidity in concentrate & Δp
- ❑ Clear nucleation induction time

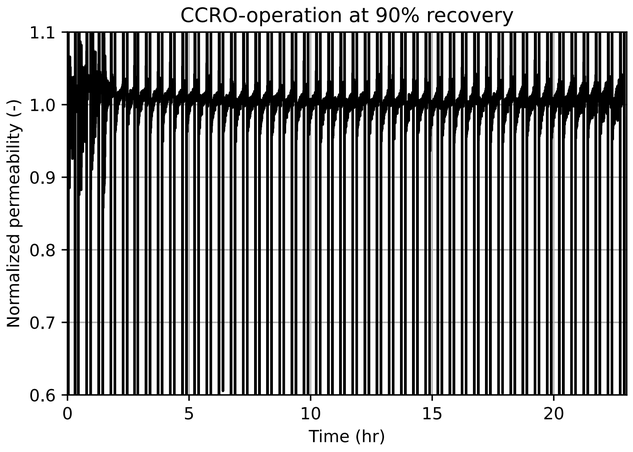


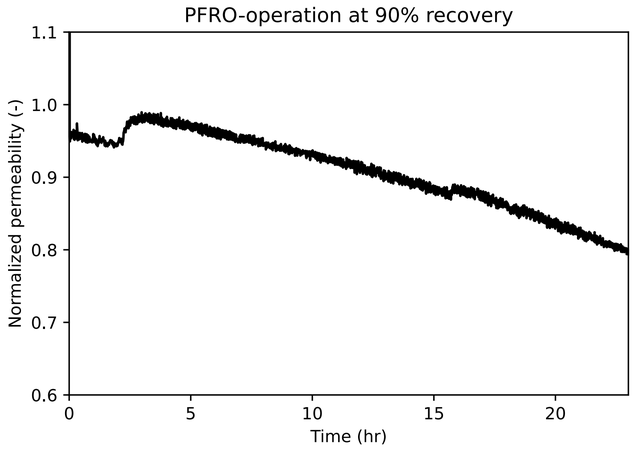
Dense $CaCO_3$-layer on the concentrate turbidity sensor

CCRO operation:

No signs of $CaCO_3$-scaling at critical recovery conditions within CC-Mode for 24 hours







Conclusion

- ❑ **Scaling was experienced at much higher recoveries, i.e., higher concentrations than predicted**.
- ❑ Occurrence of **scaling was indicated by a clear induction time**. Concentrate pH (and in some cases the turbidity) as reliable parameter to track $CaCO_3$-scaling before other parameters (e.g., permeability, pressure loss, retention, conductivity) showed signs of scaling
- ❑ **Critical recovery** was determined in **PFRO operation** and found at **90% at 20 LMH** with heavy **$CaCO_3$-scaling after 2 hours**.
  CCRO showed no scaling within CC-mode at critical recovery conditions for more than 24 hours.
- ❑ Next steps: CCRO-operation at **overall same conditions, i.e., same average flux and recovery as PFRO**.
  → As a consequence in **CC-mode a higher recovery and flux** compared to PFRO is needed to **compensate (unproductive) flushing**.

This research was conducted in the framework of the project KonTriSol (https://kontrisol.de/). KonTriSol is funded by the Federal Ministry of Education and Research of Germany (BMBF) and co-financed by the German Technical and Scientific Association for Gas and Water (DVGW). Open access funding enabled and organized by project DEAL.

Bundesministerium für Bildung und Forschung

DVGW KONTRISOL

An Initiative of the Federal Ministry of Education and Research WavE Water Technologies: Reuse

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