



**EUROMED 2024**

**Desalination for Clean Water and Energy**

**6–9 May 2024**

**Four Seasons Hotel, Sharm El Sheikh, Egypt**

## **Modification of PV Driven Single Stage RO to a Semi-Batch Closed Loop RO**

Presenter: Vinay Narayan Hegde

Co-authors: Dr. Joachim Went, Mohammadhassan Abbasigevarand  
Dr. Joachim Koschikowski, Prof. Dr. Werner Platzer

# Agenda

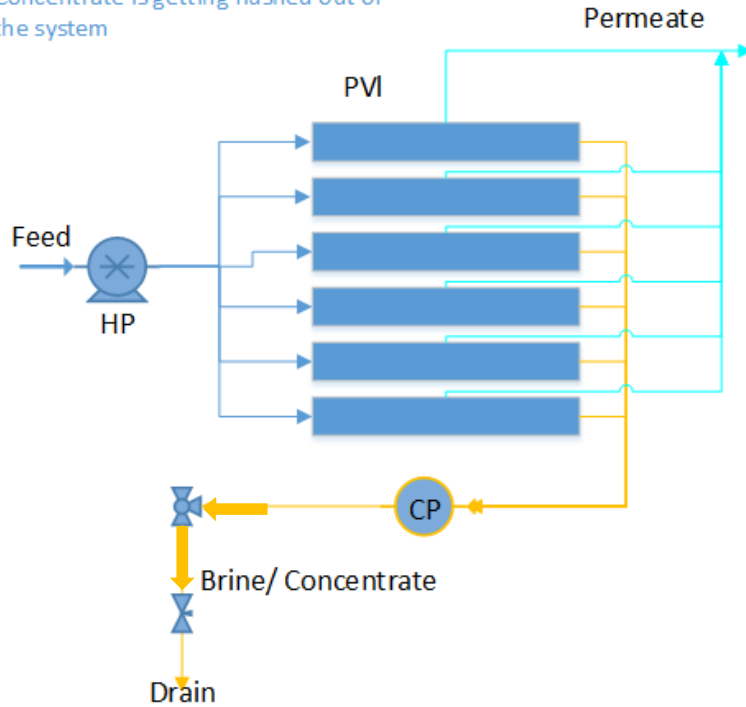
- Semi-Batch RO or Close Loop RO (CLRO)
- HighRec Project: Motivation and Technical Background
- System Design: CLRO Tool
- Pilot System Specification and Modification
- Installation, Commissioning and Operation
- Result and Lesson Learnt
- Conclusion



# Semi-Batch RO or Closed Loop RO (CLRO)

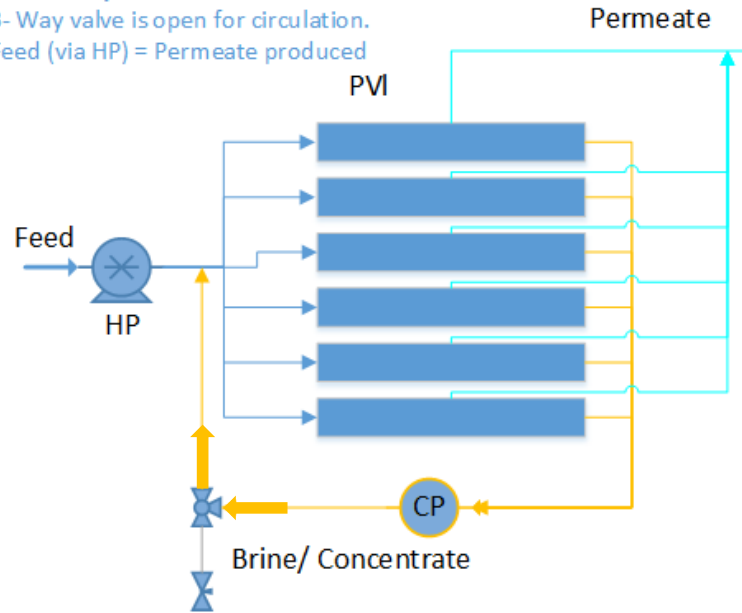
## Plug Flow mode:

3- Way valve is open for drain.  
Concentrate is getting flushed out of the system



## Closed loop mode:

3- Way valve is open for circulation.  
Feed (via HP) = Permeate produced



## Legend:

PVI : Pressure vessel with membrane elements  
HP: High pressure pump  
CP: Circulation pump

## CLRO:

Two operation points for high-pressure pump:

- PF Mode
- CL Mode



# HighRec Project: Motivation and Technical Background

## Drawbacks of state-of-the-art brackish water desalination technologies:

- Energy demand and associated CO<sub>2</sub> emissions (1.5 to 4 kWh/m<sup>3</sup>, depending on salinity)
- Cannot adapt to the fluctuation of raw water salinity
- Recovery ratio is limited
- Demand for intensive pre-treatment
- High amount of brine production

### The HighRec Consortium:



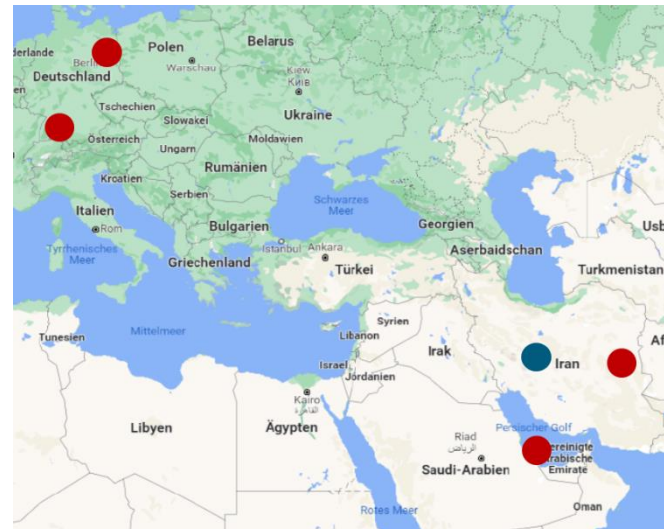
دانشگاه بیرجند  
University of Birjand

Isfahan University of Technology



Middle East Regional Water  
Research Cooperation Program

GEFÖRDERT VOM  
Bundesministerium  
für Bildung  
und Forschung





# HighRec Project: Motivation and Technical Background

## The objectives:

- Development of sustainable brackish water desalination
  - Adaptable to fluctuating feed water concentration
  - Renewable energy coupling
  - High yield and respectively high recovery
- Development, construction and operation of High Recovery - Solar PV driven demonstration system
  - Low cost
  - Robust
  - Easy retrofit
  - Direct coupling to PV



# HighRec Project: Motivation and Technical Background

## Technical Solution

- **Chosen desalination system: Closed Loop RO system**

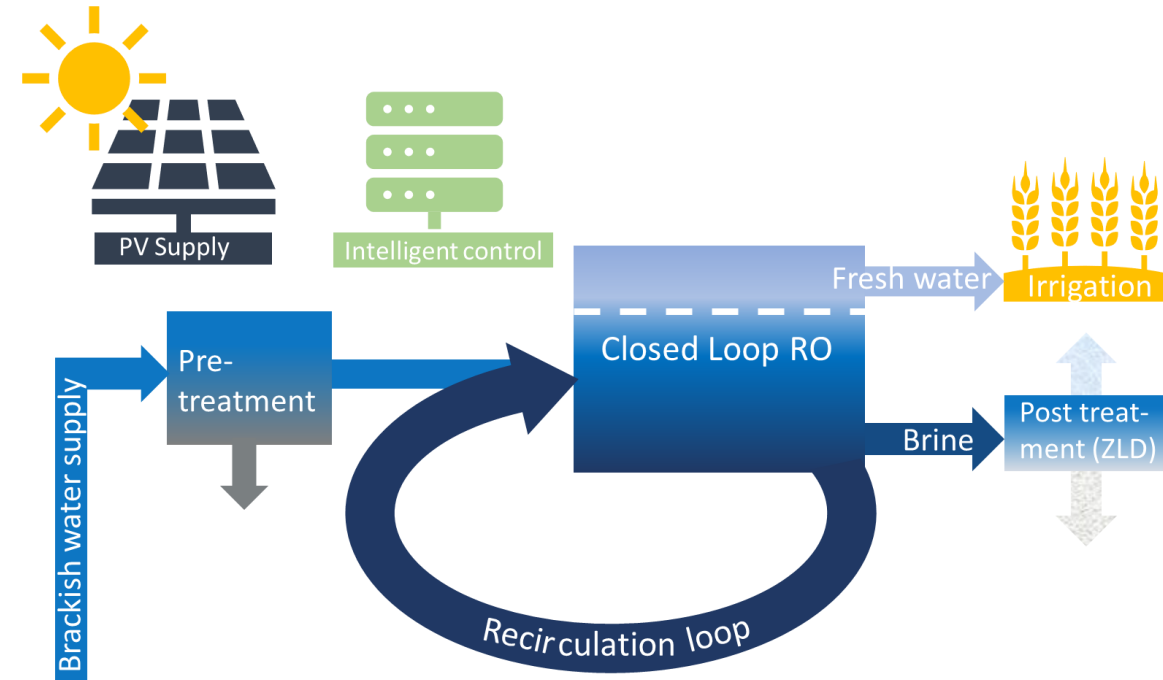
Modification of existing single stage RO to semi-batch CLRO

- **Renewable Energy**

PV supply direct coupling to CLRO plant

## But

- Limitations of dimensioning tool
- Cost effective, robust and reliable PV coupling:
  - Already available for single stage RO: Direct DC feed without an inverter (DC/AC)
  - Not tried for transient load like CLRO



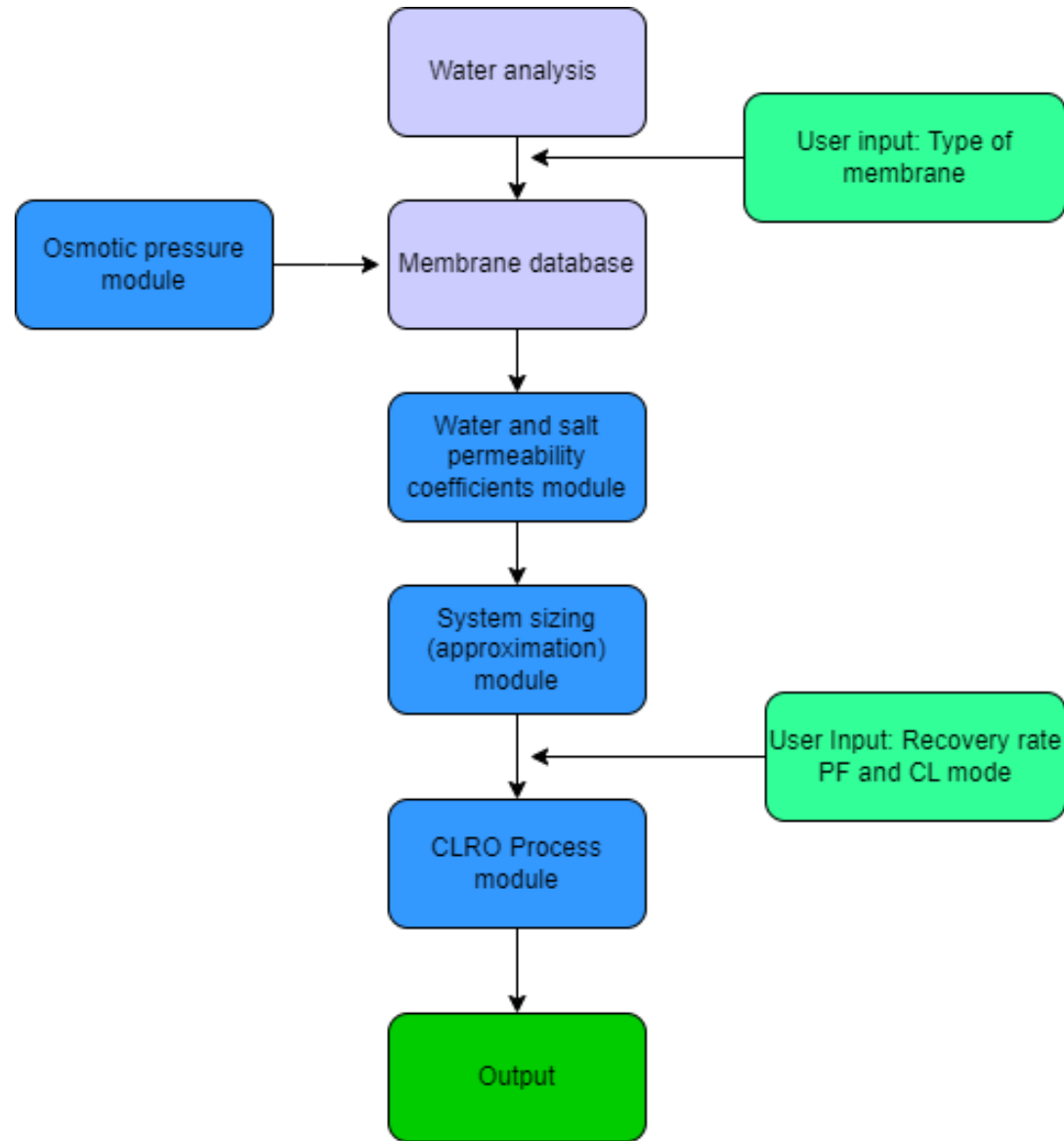
## Idea for in-house Tool

- Overcome the limitations of dimensioning tools of commercial RO membrane producers
  - Limited membrane selection
  - Parameters are fixed
  - Does not provide design recommendations and help
- Obtain element by element performance data for all cycles
- Flexible design and automation of the process:  
Operation based on limitations- Permeate quality, recovery rate, water demand, energy supply



# System Design: CLRO Tool

## Program Flow Chart





# System Design: CLRO Tool

## Retrofit approach for Standard Single Stage RO to CLRO

	Company A	Company B
Production capacity	1.5 m <sup>3</sup> /h	1.3 m <sup>3</sup> /h
Feed flowrate	3.5 m <sup>3</sup> /h	3.9 m <sup>3</sup> /h
Recovery rate	43 %	35%
Maximum pressure	65 bar	80 bar
No. of pressure vessels	1	4
Membrane element	2 x 8" – LG Chem, LG SW 400 R	8 x 4" – FilmTec SW30-4040



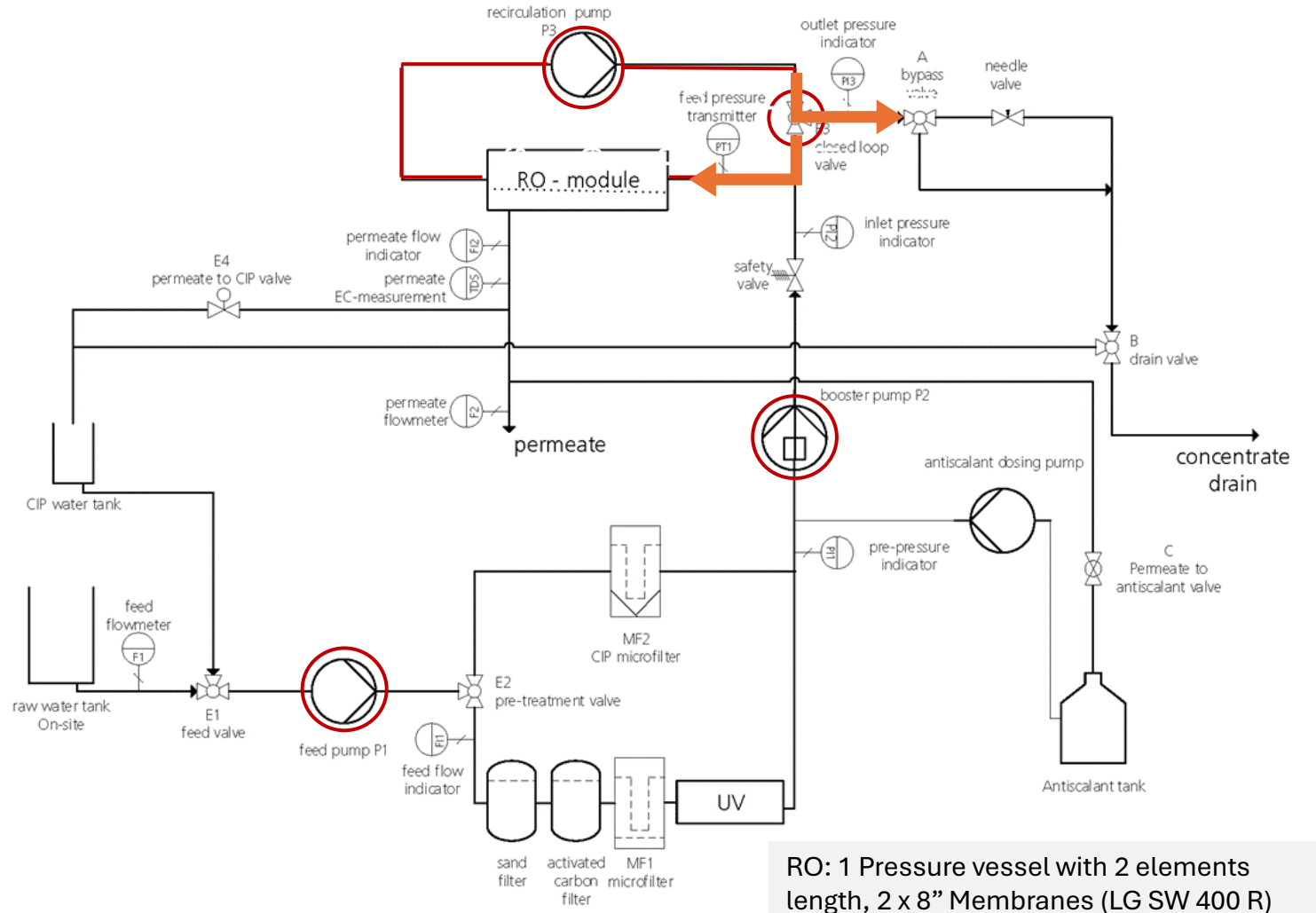
## Modification of Standard Single Stage RO to CLRO: Design Parameters

### Conventional RO System

- Production capacity: 1.5 m<sup>3</sup>/h
- Feed flow: 3.5 m<sup>3</sup>/h
- Recovery Ratio (RR): 43%
- Maximum pressure: 50 bar

### Modified Demo CLRO System

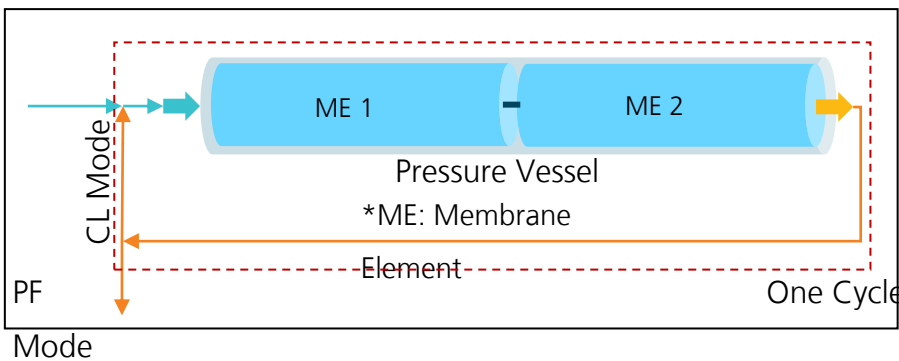
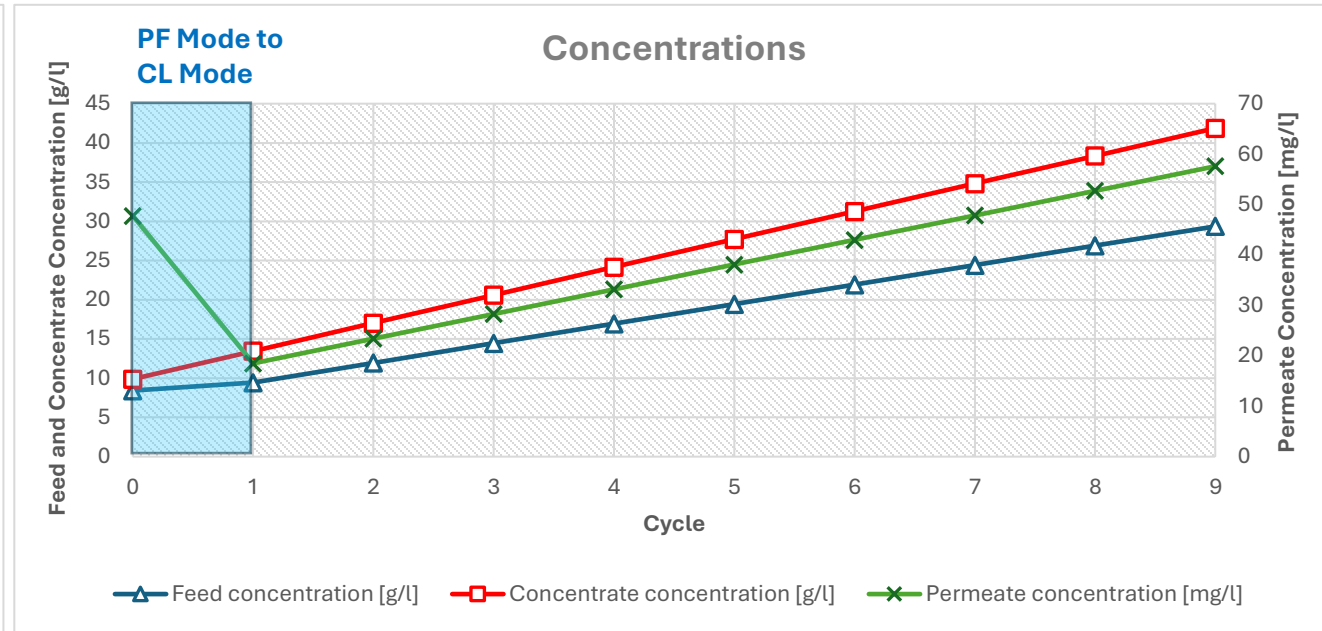
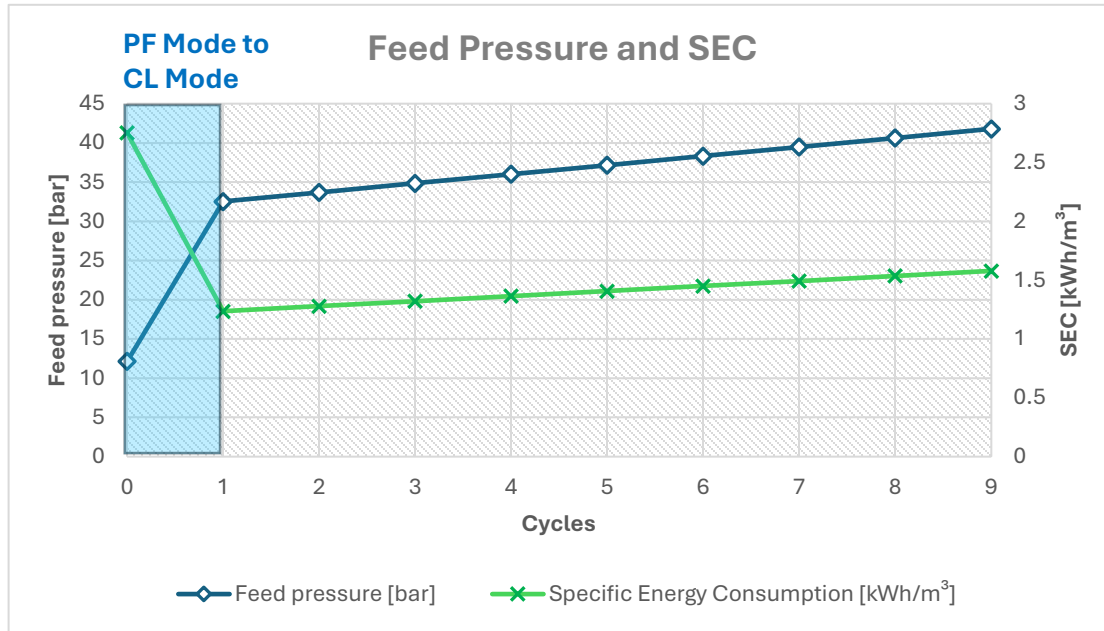
- Net production capacity: 1.9 m<sup>3</sup>/h
- Net feed flow: 2.5 m<sup>3</sup>/h
- Net Recovery Ratio (RR): 76%
- Maximum pressure 45 bar
- Net SEC\*: 1.5 kWh/m<sup>3</sup>



RO: 1 Pressure vessel with 2 elements length, 2 x 8" Membranes (LG SW 400 R)

\*For SEC calculation only power consumption from HPP + RCP are considered

## Modification of Standard Single Stage RO to CLRO: Simulation Result – One pass



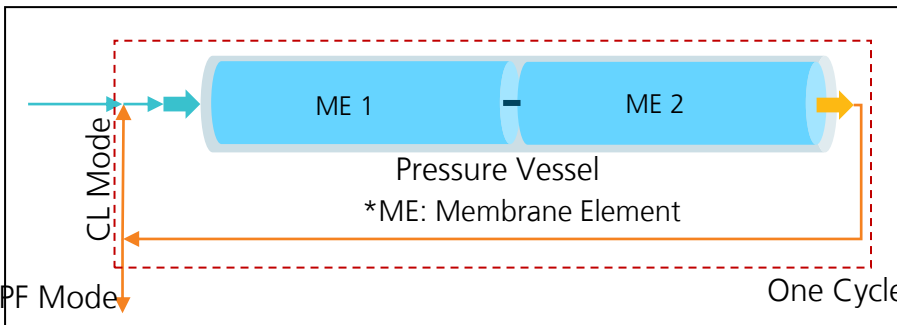
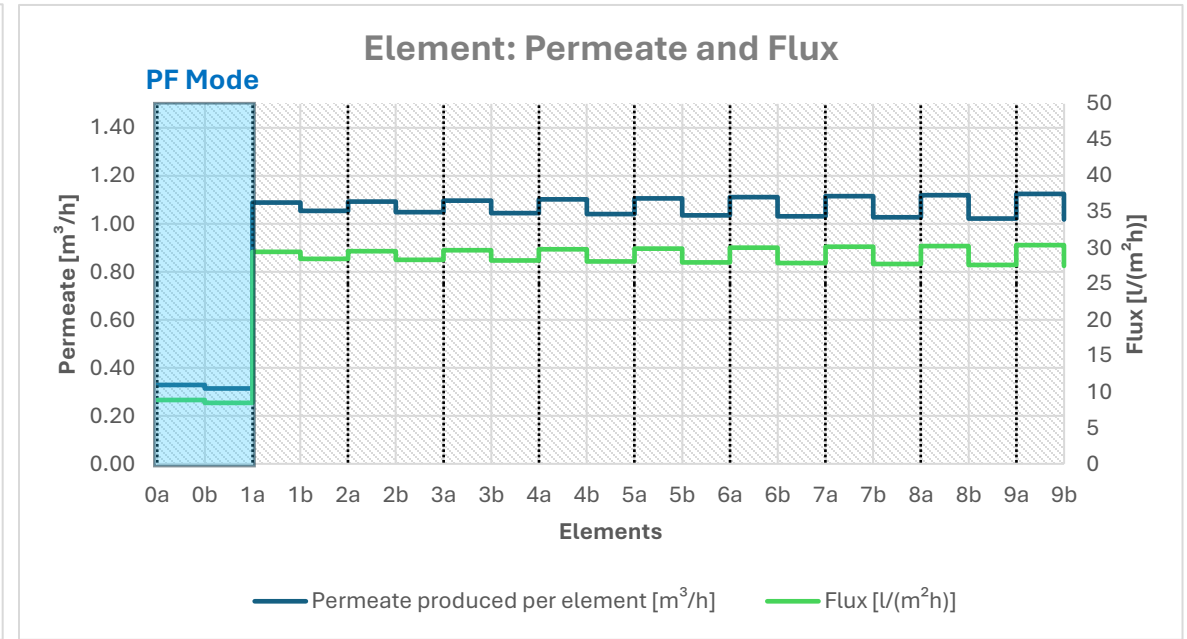
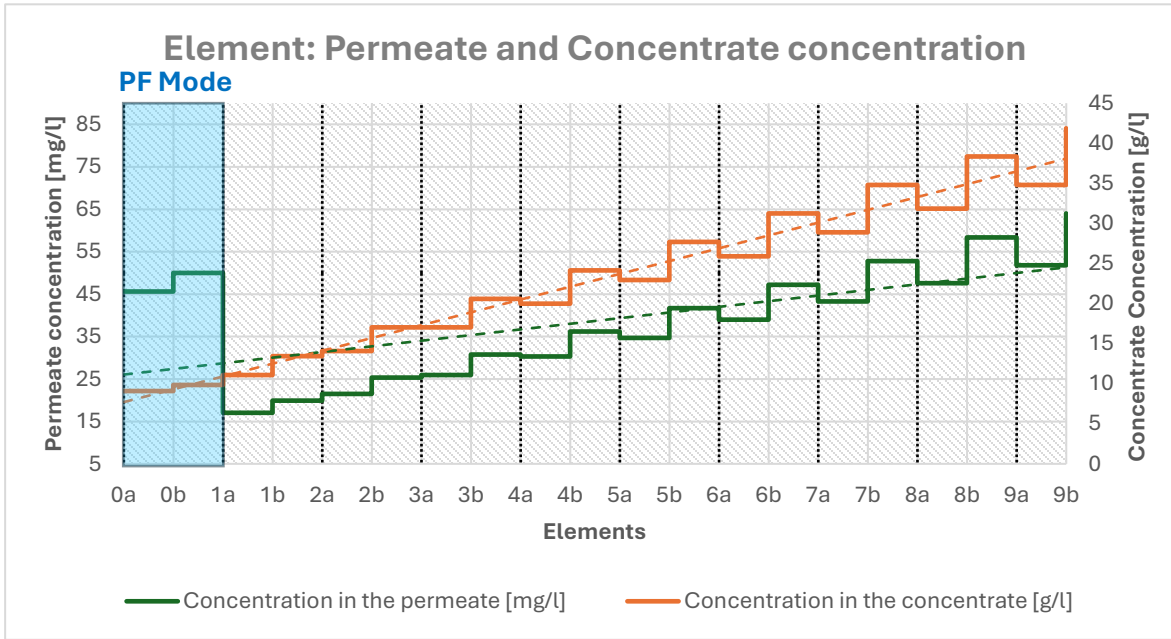
- PF Recovery: 15%
- CL Recovery: 30%
- System Volume: 47 l

- PF Time and Feed pressure: 46 s, 12 bar
- Pressure threshold for CL to PF switch: 42 bar

### Modified CLRO System

- Net production: 1.9 m<sup>3</sup>/h
- Net feed flow: 2.5 m<sup>3</sup>/h
- Net Recovery Ratio (RR): 76%
- Maximum feed pressure: 42 bar
- Net SEC: 1.5 kWh/m<sup>3</sup>

## Modification of Standard Single Stage RO to CLRO: Simulation Result - Elementwise



### Modified CLRO System

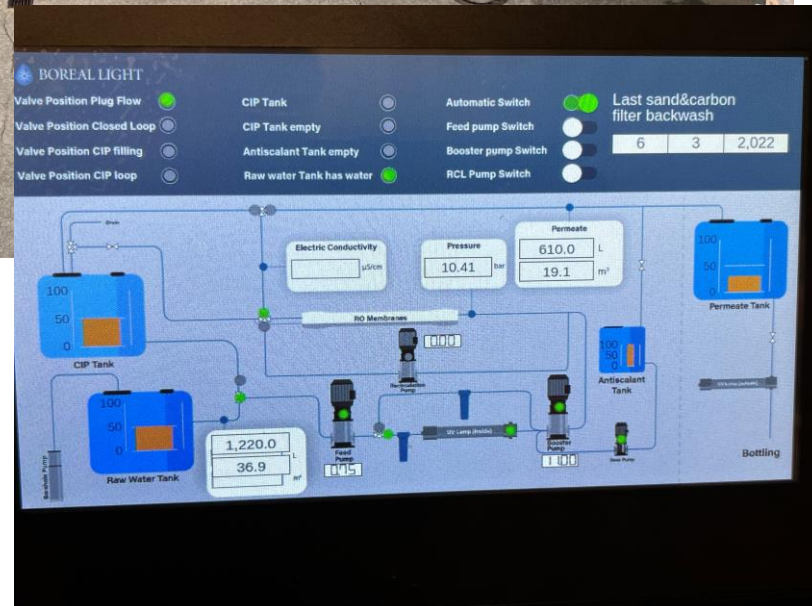
- Average permeate concentration: 38 mg/l
- Final concentrate concentration: 42 g/l
- Average flux: 27 l/(m²h)





# Installation, Commissioning and Operation

## Installation and Commissioning: First commissioning at Fraunhofer ISE (July/August 2023)





# Installation, Commissioning and Operation

## Installation and Commissioning: Commissioning at Agrico, Qatar (October 2023)



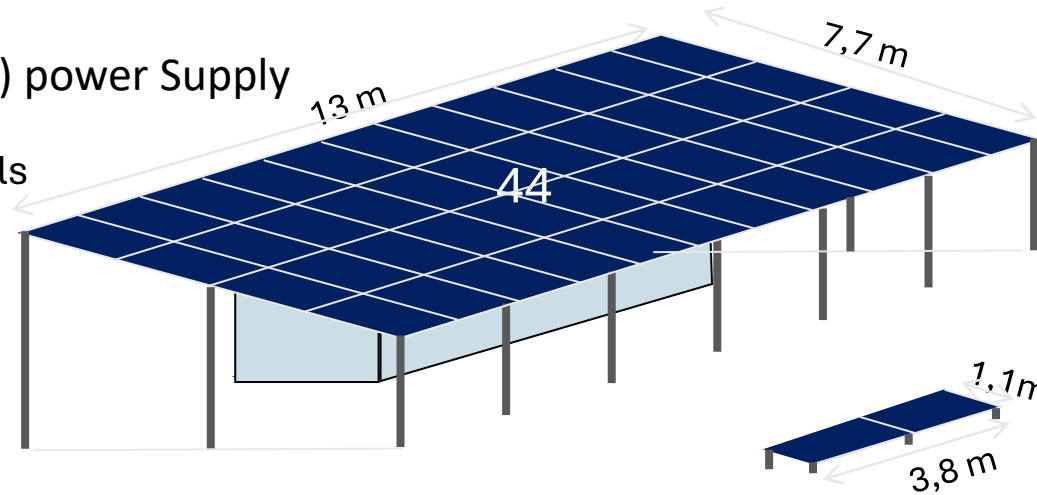
# Installation, Commissioning and Operation

## Installation and Commissioning: Commissioning at Agrico, Qatar (October 2023) – Mounting PV Panels

Hybrid (AC / Solar) power Supply

4 strings of 11 panels

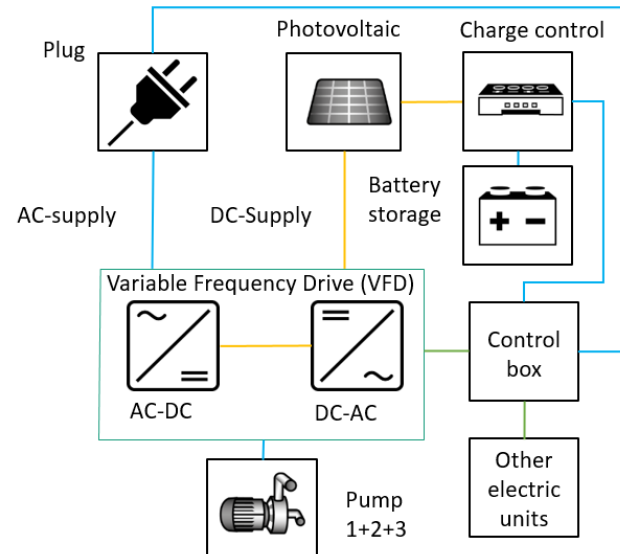
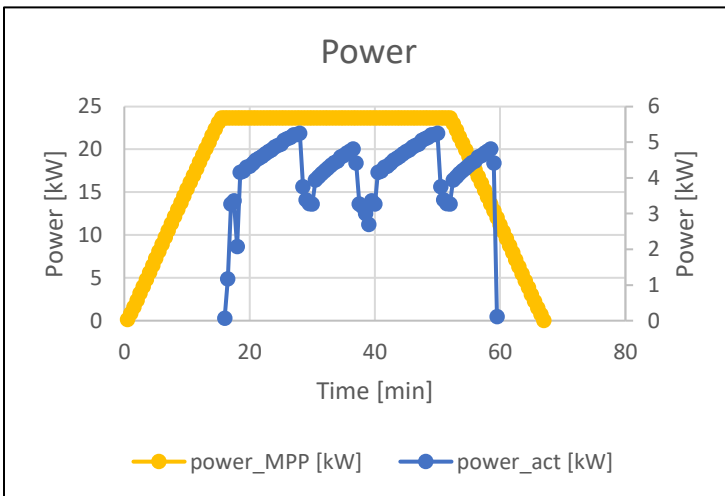
$P_{max}: 20,24kW_p$



Power consumption RO system  $P_{max} : 6 kW$



720W<sub>p</sub> / 24V battery storage system  
as permanent backup for PLC





# Installation, Commissioning and Operation

## Operation (since October 2023): Remote monitoring system

Fraunhofer

Gerät: 0141\_Fraunhofer < 05.12.2023 00:00:00 - 06.12.2023 00:00:00 > Aktualisieren ▾

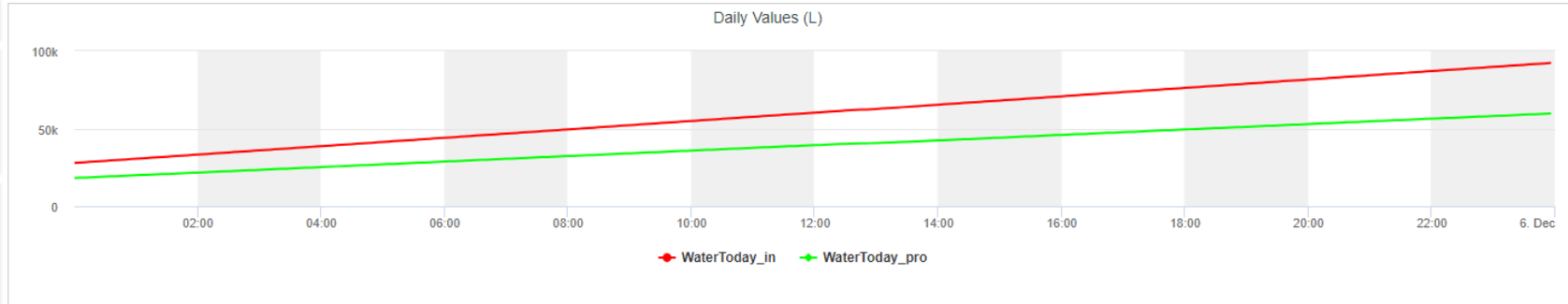
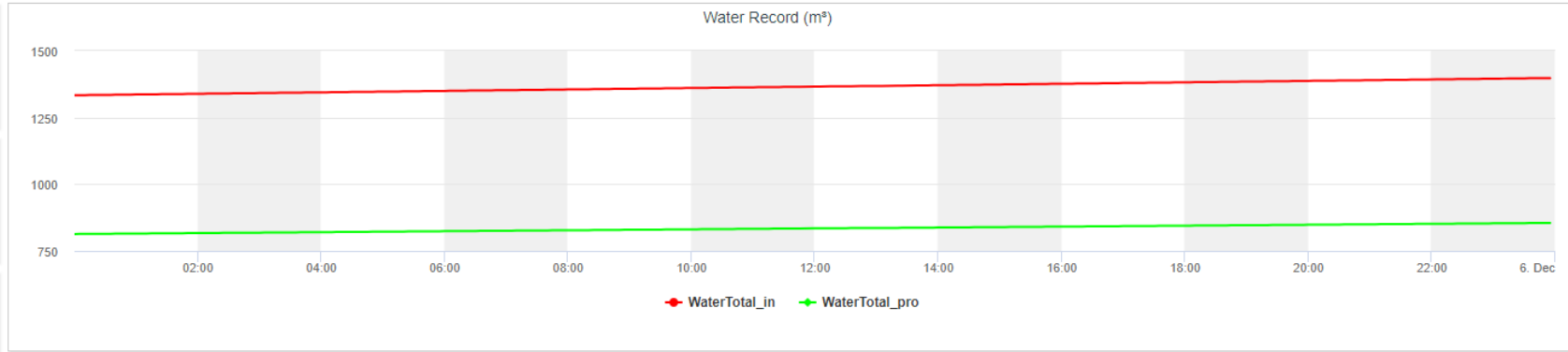
Sw-Auto

Sw-Feed

Sw-Booster

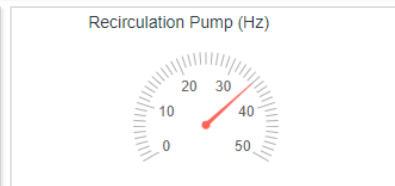
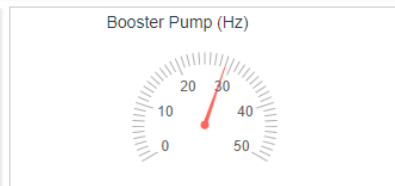
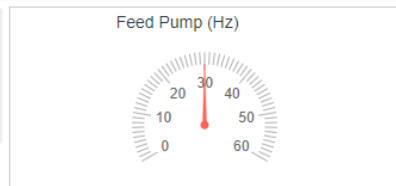
Sw-Recirculation

Sw-CIP



Pressure (Bar)

**31.14**



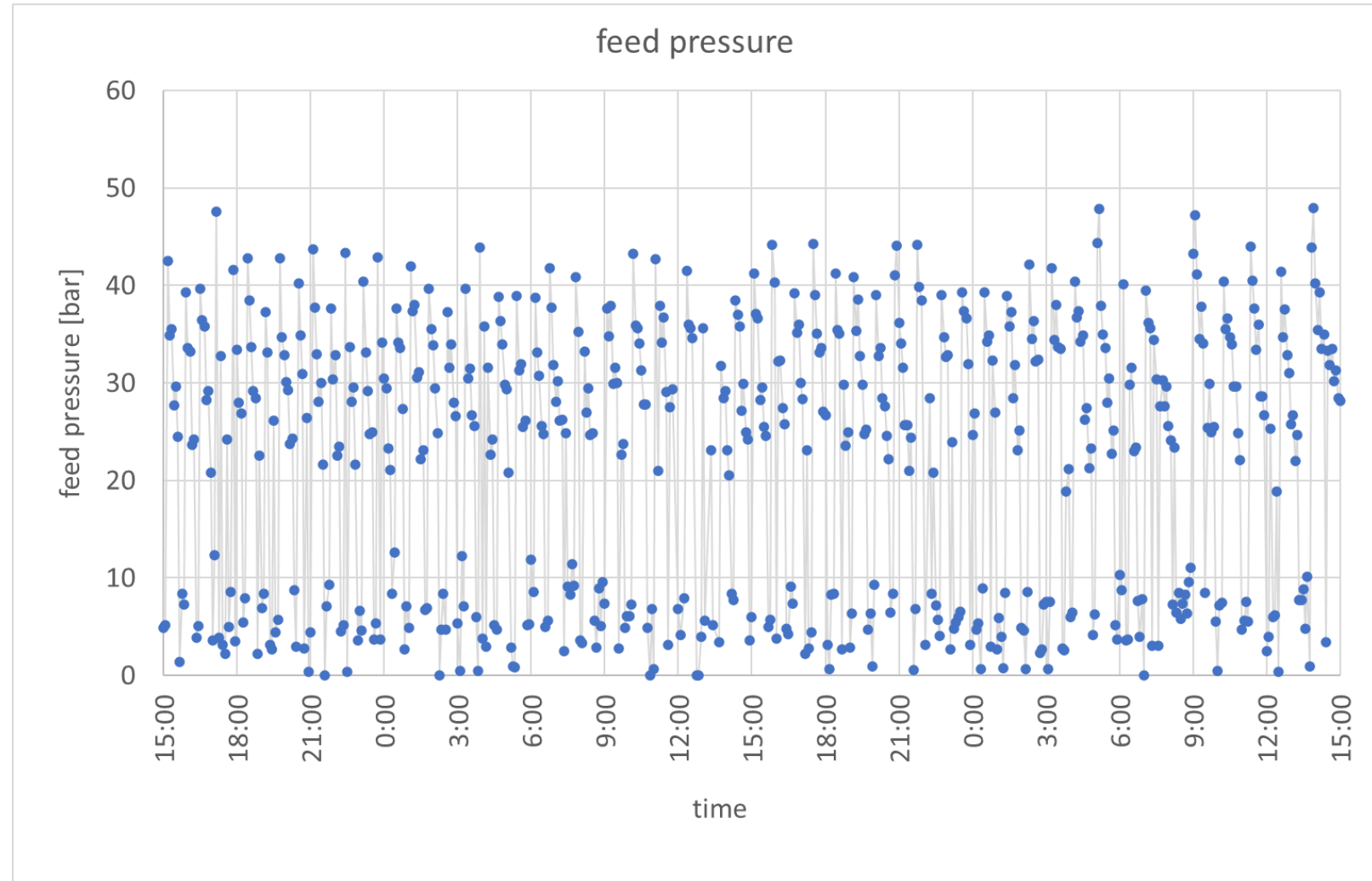
Conductivity (µS/cm)

**81.09**



## Operation (since October 2023): Feed Pressure

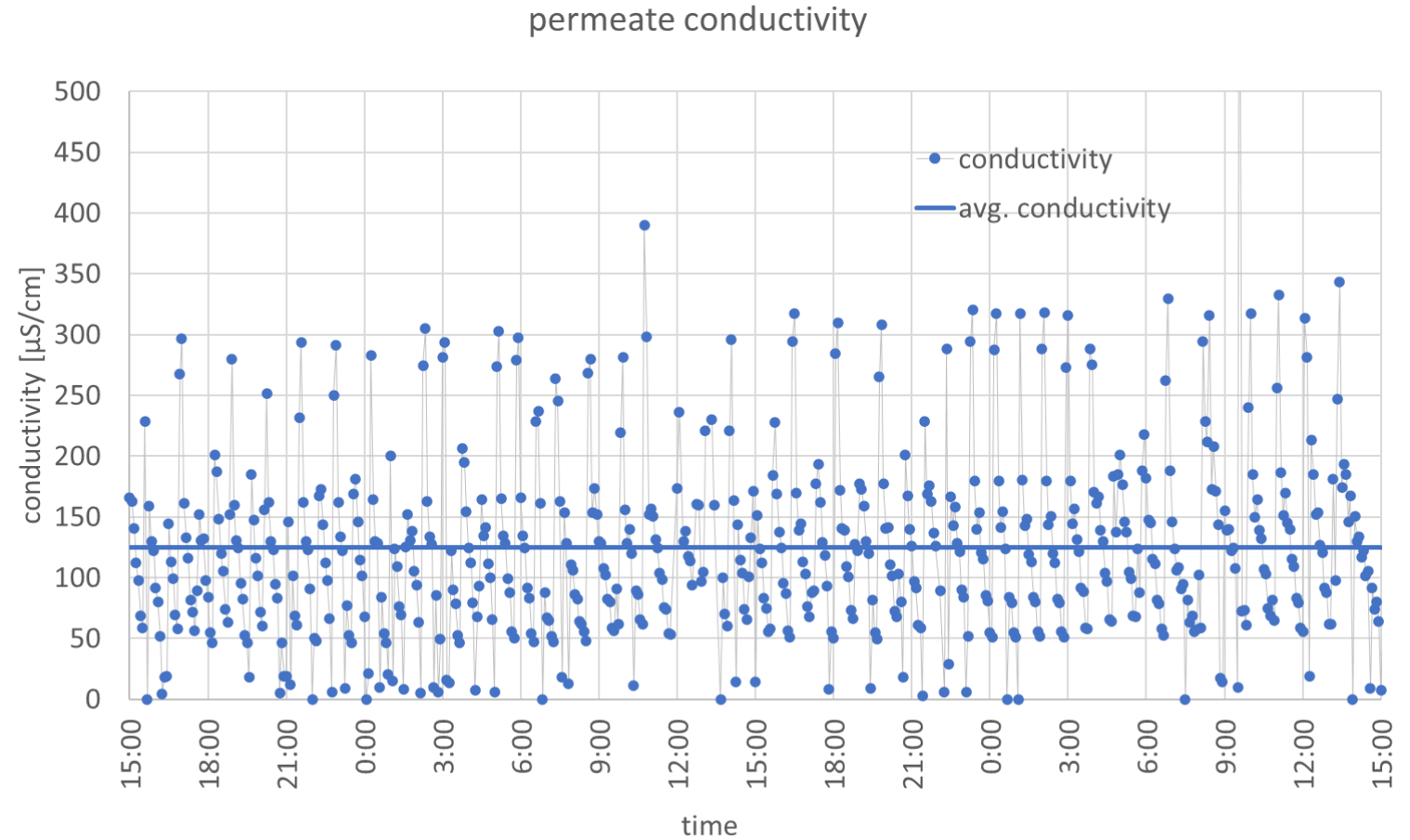
- About 10 bar during PF-mode
- Between 20- 45 bar during CL-mode



# Installation, Commissioning and Operation

## Operation (since October 2023): Permeate conductivity

- Permeate conductivity: Mean value is 125  $\mu\text{S}/\text{cm}$

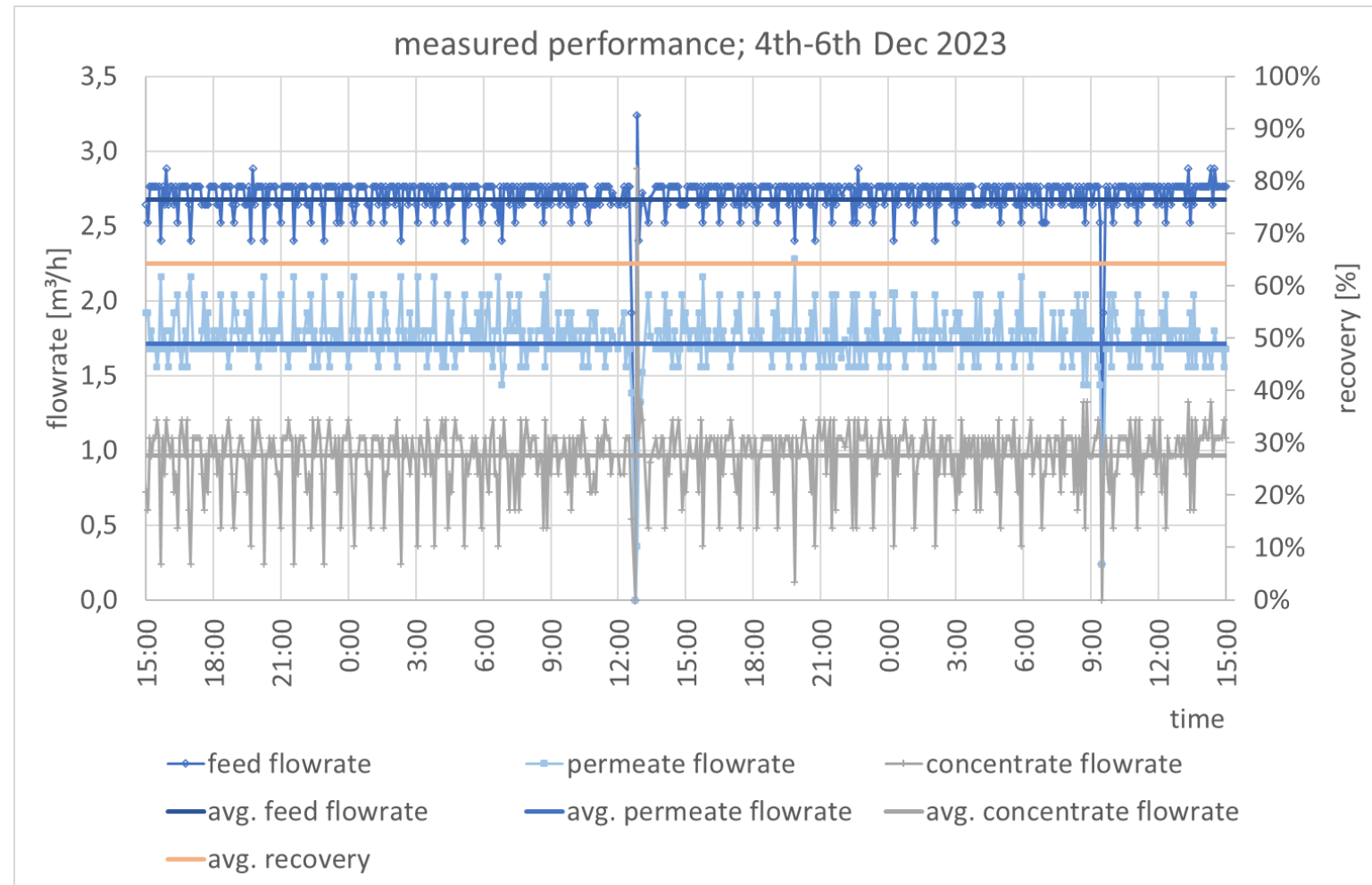




# Installation, Commissioning and Operation

## Operation (since October 2023): Flow rates

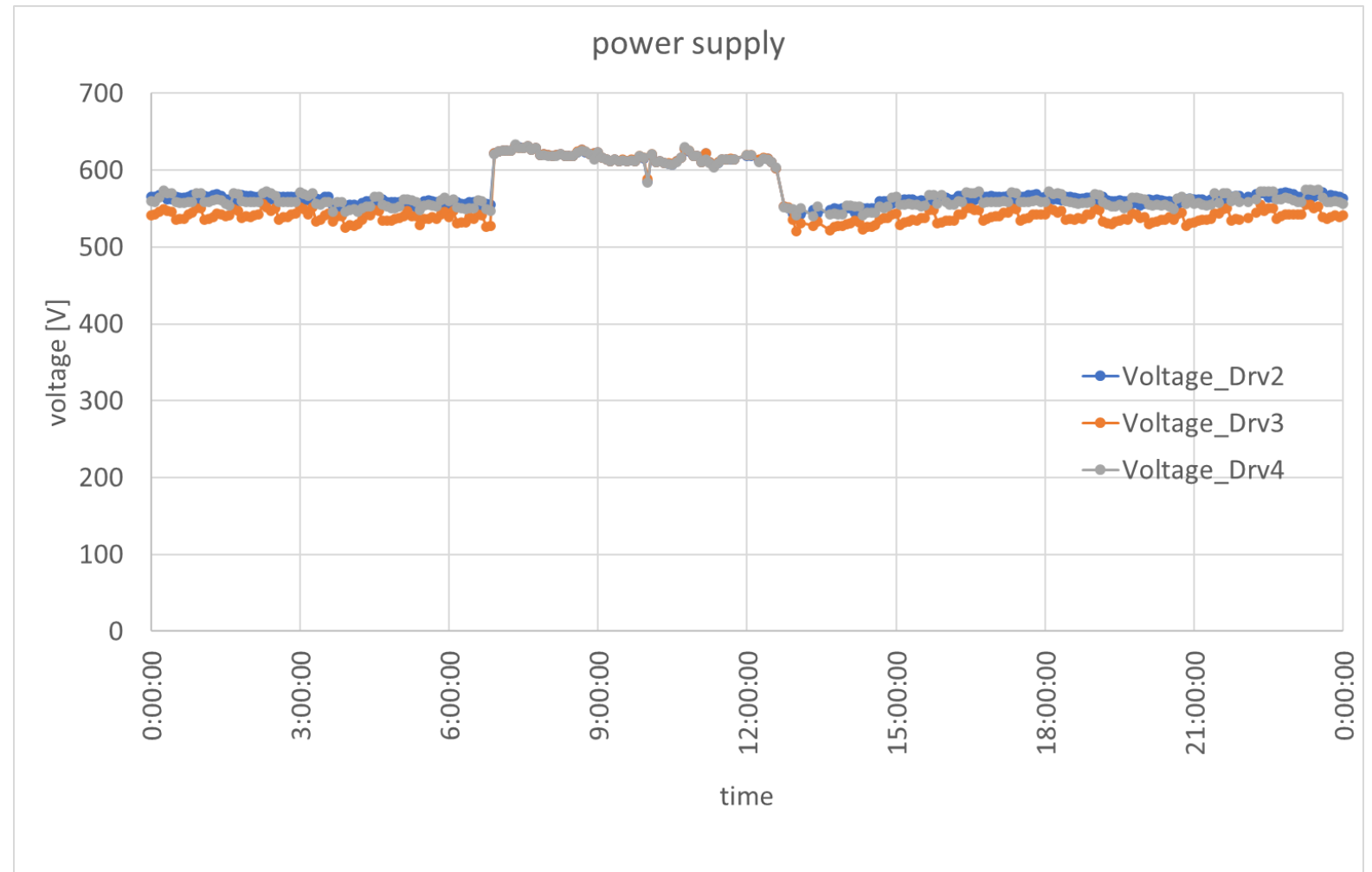
- Mean values in this period:
  - Feed  $2.67 \text{ m}^3/\text{h}$
  - Permeate  $1.71 \text{ m}^3/\text{h}$
  - Concentrate  $0.97 \text{ m}^3/\text{h}$
  - Recovery  $64.30\%$



# Installation, Commissioning and Operation

## Operation (since October 2023): Power supply

- Times of switching not optimized; depends on the availability of operators



## Result

	Unit	Design	Measurement	Comment
Avg. permeate flowrate	[m <sup>3</sup> /h]	1.89	1.71	<ul style="list-style-type: none"> <li>Duration of PF-operation 80sec instead of 46sec</li> </ul>
SEC	[kWh/m <sup>3</sup> ]	1.48	2.19	<ul style="list-style-type: none"> <li>Too long PF mode</li> <li>Too optimistic pump efficiencies</li> <li>Pre-treatment not included in design calculation</li> </ul>
Recovery	[%]	75.8	64.3	<ul style="list-style-type: none"> <li>Longer PF-mode</li> </ul>

When simulation is conducted with 80 s PF mode

- Avg. permeate flow rate = 1.78 m<sup>3</sup>/h (3.9% difference to measured value)
- Net recovery rate = 69.7 % (7.7% difference to measured value)

Pump efficiencies:

High pressure pump = 75%

Recirculation and feed pump = 45%

\*The second phase of demonstration in Iran could not happen due to sanctions



## Lesson Learnt

- Reliable prediction from the in-house dimensioning and performance evaluation tool
- Retrofitting of existing RO system to semi-batch CLRO just with:
  - Variable frequency drive pumps
  - Recirculation pump
  - Automated 3-Way valve for closing the loop and draining out the concentrate
- Retrofitting is budget friendly for small RO desalination units
- PV direct coupling concept is reliable even without inverter
- Simple pretreatment - Sand filters and micro filtration
- Scaling prevention: Antisclant (only chemical used), Flow reversal in closed loop, CIP before and after the operation



## Lesson Learnt

- Peaks in the permeate concentration is observed during switching between CL mode to PF Mode
  - ✓ *Probably be prevented by adjusting the sealing concept of membrane elements, for example by using shimmers*
- High wear and tear of high pressure pump (plunger pump)
  - ✓ *Additional or other type of booster pump for PF mode or PF mode with pre-pressure pump (10-12 bar)*
- The pilot system is built with a very simple and cost effective approach: but offered a lot of learnings
- Improvements can be done for new scientific findings and make the system commercial:
  - ✓ *Automated switching on/off, e.g. via irradiation sensor*
  - ✓ *MPP control strategy*
  - ✓ *Automated cleaning cycles*





# Conclusion

- Design tool is suitable for using any membrane element for system planning
- Retrofit approach for existing small single stage RO to semi-batch CLRO is possible with a little effort
- CLRO is a good solution for high recovery, fluctuating raw water quality and robust against scaling even without special pre-treatment
- PV coupling without inverter and frequency converter works good, robust and cost effective and reliable
- Next generation CLRO:
  - CLRO with isobaric chamber or with different type of pump
  - Automation: Utilizing the PV energy supply efficiently and make the system user friendly





## Contact

---

Vinay Narayan Hegde  
Water Treatment and Separation  
Tel. +49 761 4588-5884  
vinay.narayan.hegde@ise.fraunhofer.de

Fraunhofer ISE  
Heidenhofstraße 2  
79110 Freiburg  
www.ise.fraunhofer.de

