



Lessons Learned from Evaluation of Different Spiral Wound SWRO Membranes in Gulf Seawater

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Al-Jubail SWRO Plant





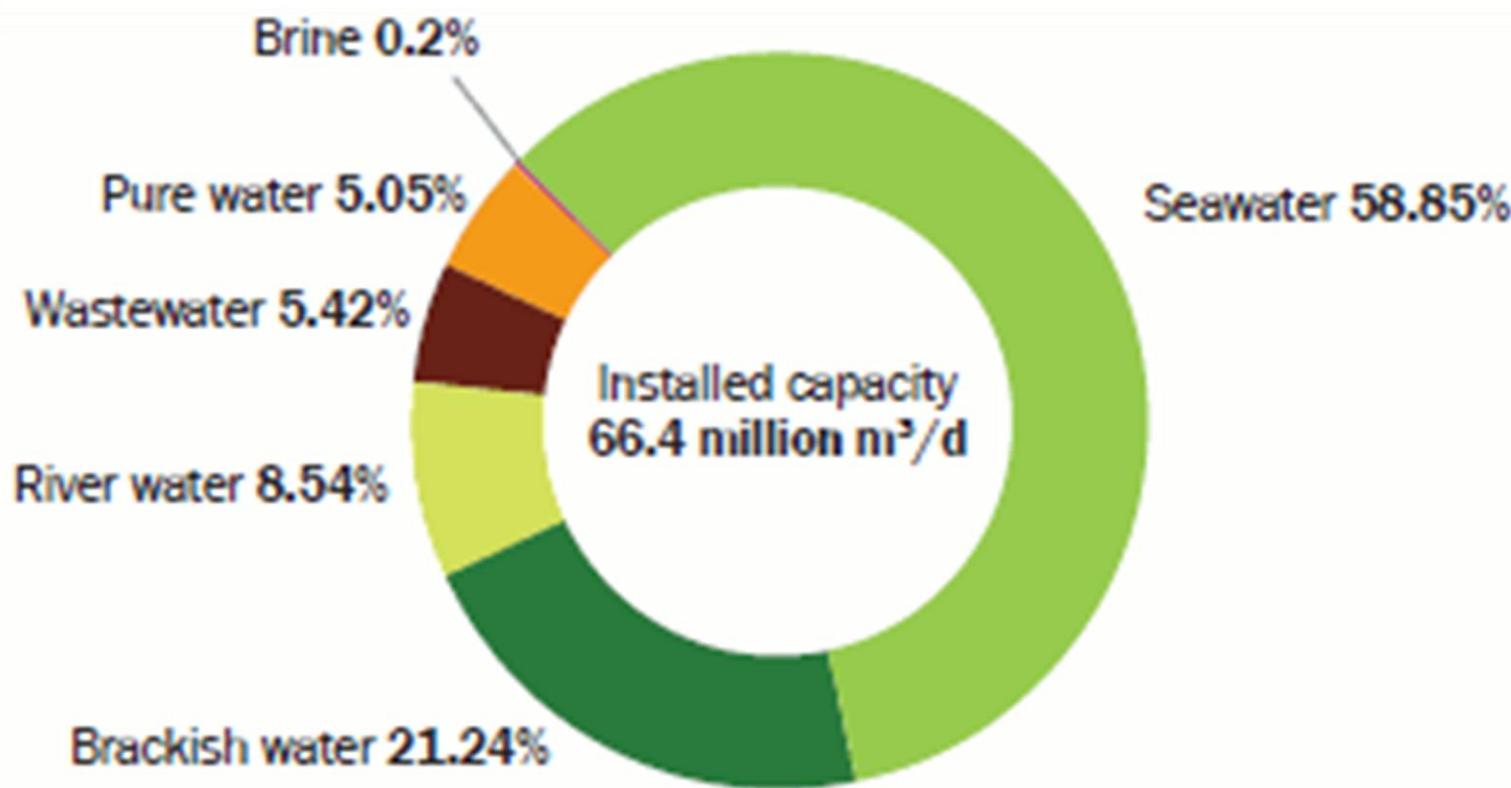
Desalination

- Water treatment processes that removes salts from saline water to produce fresh water
 - Has become a viable option for obtaining potable water
 - A total of 77.4 million m³/d in 2011
 - Includes contracted





Installed desalination plants by feed water type 2010



Source: GWI DesalData / IDA





Seawater Desalination Technologies

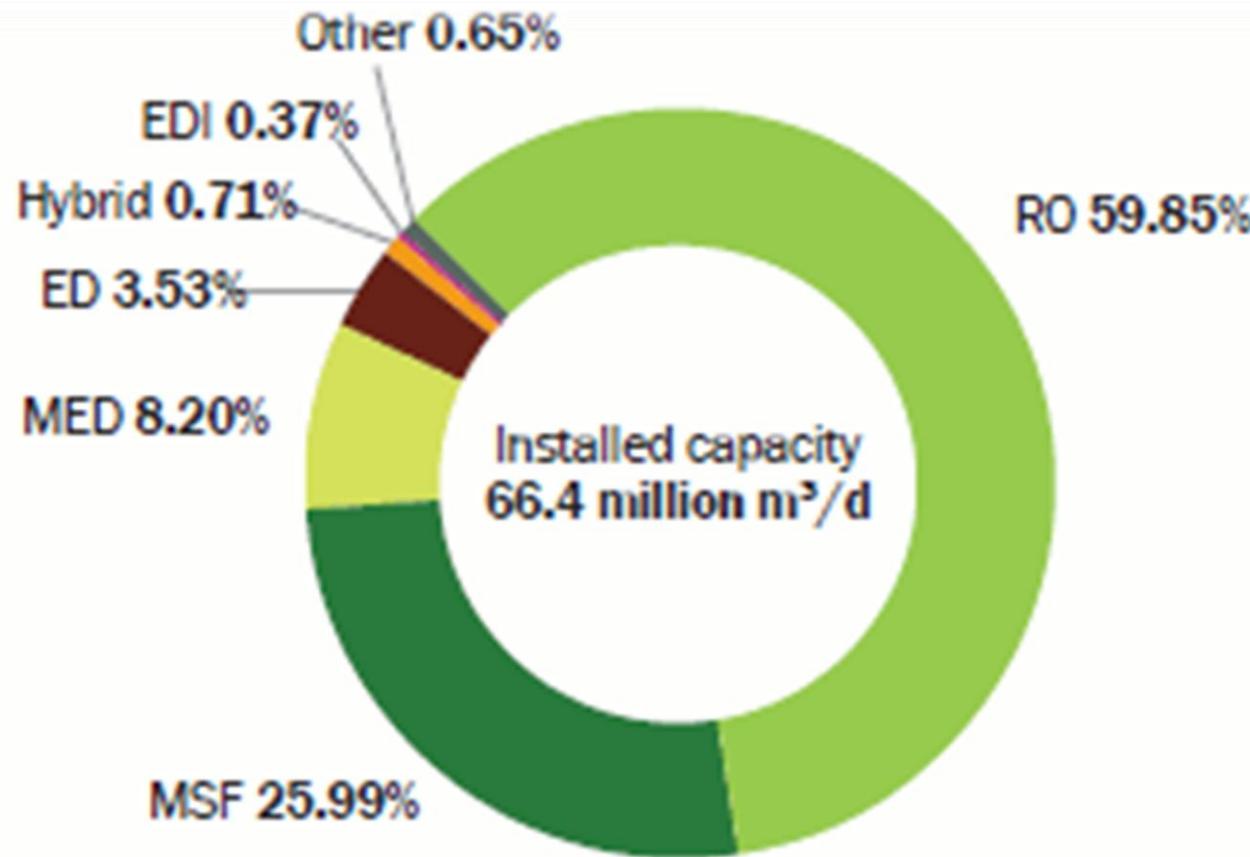
- Thermal desalination
 - Dominated over the years

- Membrane desalination
 - Tremendous growth recently





Total worldwide installed capacity by technology 2010



Source: GWI DesalData / IDA





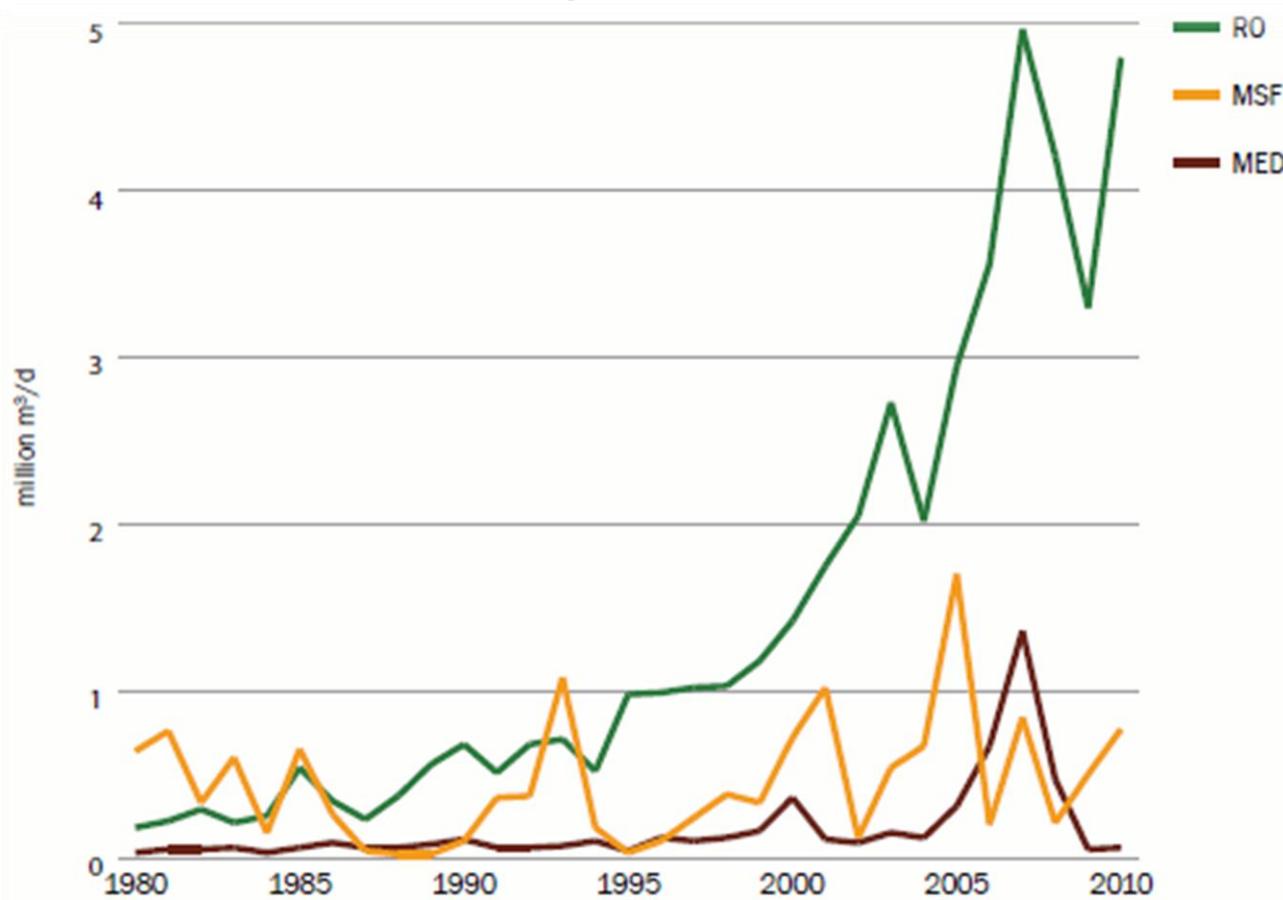
Membrane Desalination

- Remove salt ions from water by using membranes that selectively permit or prevent the passage of certain ions.
- Seawater Reverse Osmosis (SWRO) desalination
 - Increasingly popular
 - Advances in Technology





Annual new contracted seawater desalination capacity by technology during 1980 - 2010



Source: GWI DesalData / IDA





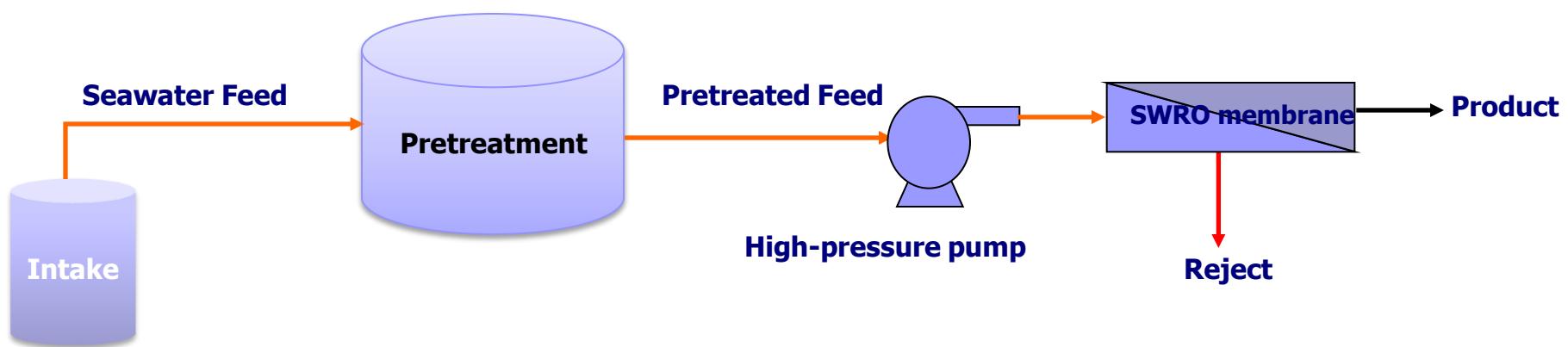
Major Advantages of Membrane Processes

- Relatively Simple
- Cost effective
 - Due to advances in energy recovery devices and membranes
- Modular – Expandable
- Relatively small footprint





Schematic Diagram of SWRO Desalination Process





SWRO Membranes

- Classified based on
 - Chemical composition
 - Configuration





Classification of RO Membranes

- Based on chemical composition

- Cellulose acetate

- Hydrophilic
 - Chlorine resistant
 - Easily hydrolysable
 - Poor chemical stability
 - Relatively cheap

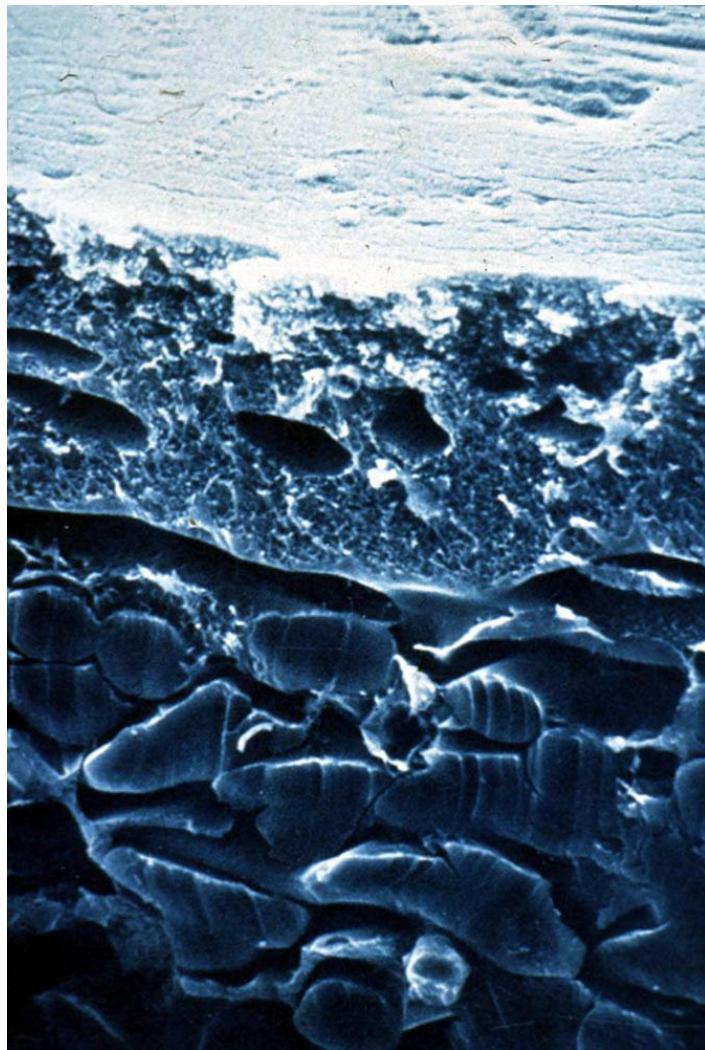
- Polyamide, Thin film composites (TFC)

- Sensitive to chlorine
 - Hydrophobic





TFC RO Membrane Structure



**Polyamide
barrier layer**

**Polysulfone
support layer**



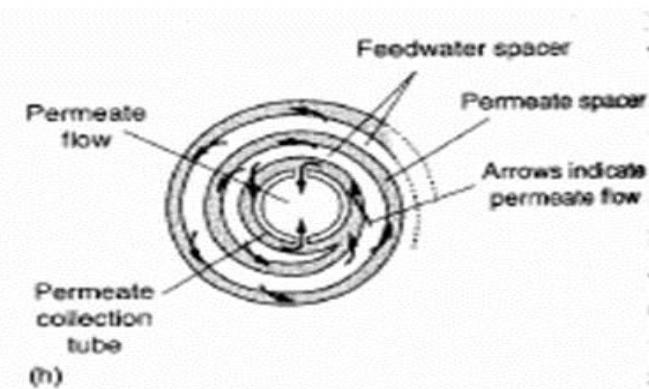
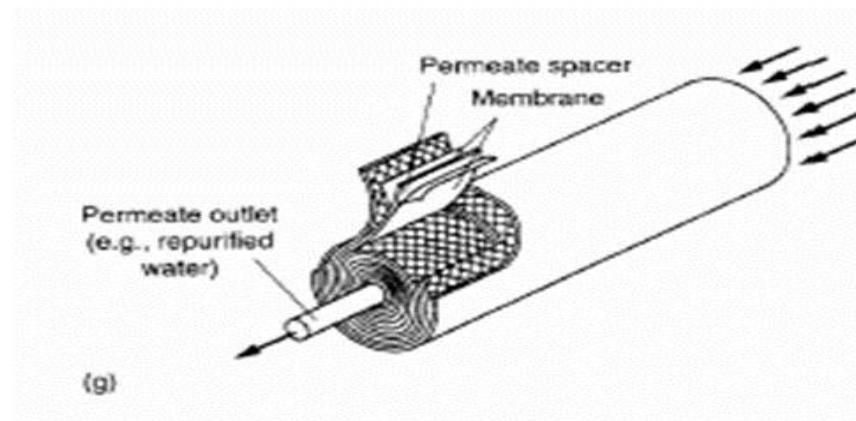


Classification of Membranes (cont.)

■ Based on configuration

□ Spiral wound

- Most widely used
- Can tolerate higher SDI
- Flow is in a spiral pattern
- Membrane envelop is spirally wound along with a feed spacer
- Filtrate is collected within the envelop and piped out



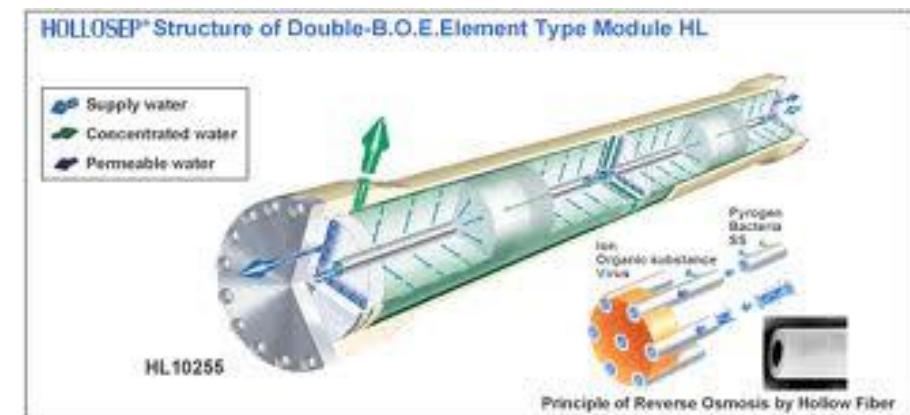


Classification of Membranes (cont.)

■ Based on configuration

□ Hollow Fine Fiber

- Need better quality feed water than spiral wound
- Consists of a bundle of hundreds and thousands of hollow fiber
- Higher packing density





Spiral wound Vs Hollow Fine Fiber

Spiral wound

- Several Manufacturers

- FilmTec
 - Hydranautics
 - Toray
 - Koch
 - GE Osmonics
 - Trisep
 - Woongjin

Hollow fine Fiber

- Limited

- DuPont – discontinued
 - Toyobo





Selection criteria of membrane

- Sustainable Performance
 - Product flow
 - Salt rejection

- Performance depends on
 - Feed water quality
 - Inherent membrane properties
 - Chemistry, spacer, membrane area etc.
 - Operation conditions
 - Flux, recovery etc.





Background

- Al-Jubail SWRO Plant
 - Commissioned during year 2000
 - A total of 15 Trains
 - 11 Trains with HFF membranes
 - 4 Trains with Spiral Wound (SW) membranes
 - DuPont discontinued production
 - Necessity for replacement
 - SW performance was not satisfactory





Background

- Evaluated performance of five different spiral wound SWRO membranes to have best option
- Several lessons were learnt from the membrane evaluation





Experimental

- Carried out on Train A
 - Along with spiral wound membranes
 - By isolating some pressure vessel and modification
 - Accommodated membranes in parallel
 - Same operation conditions as Train A
 - A total period of 14,300 hrs
 - SDI 2.32 – 4.3
 - Feed Temperature 14 – 37 °C



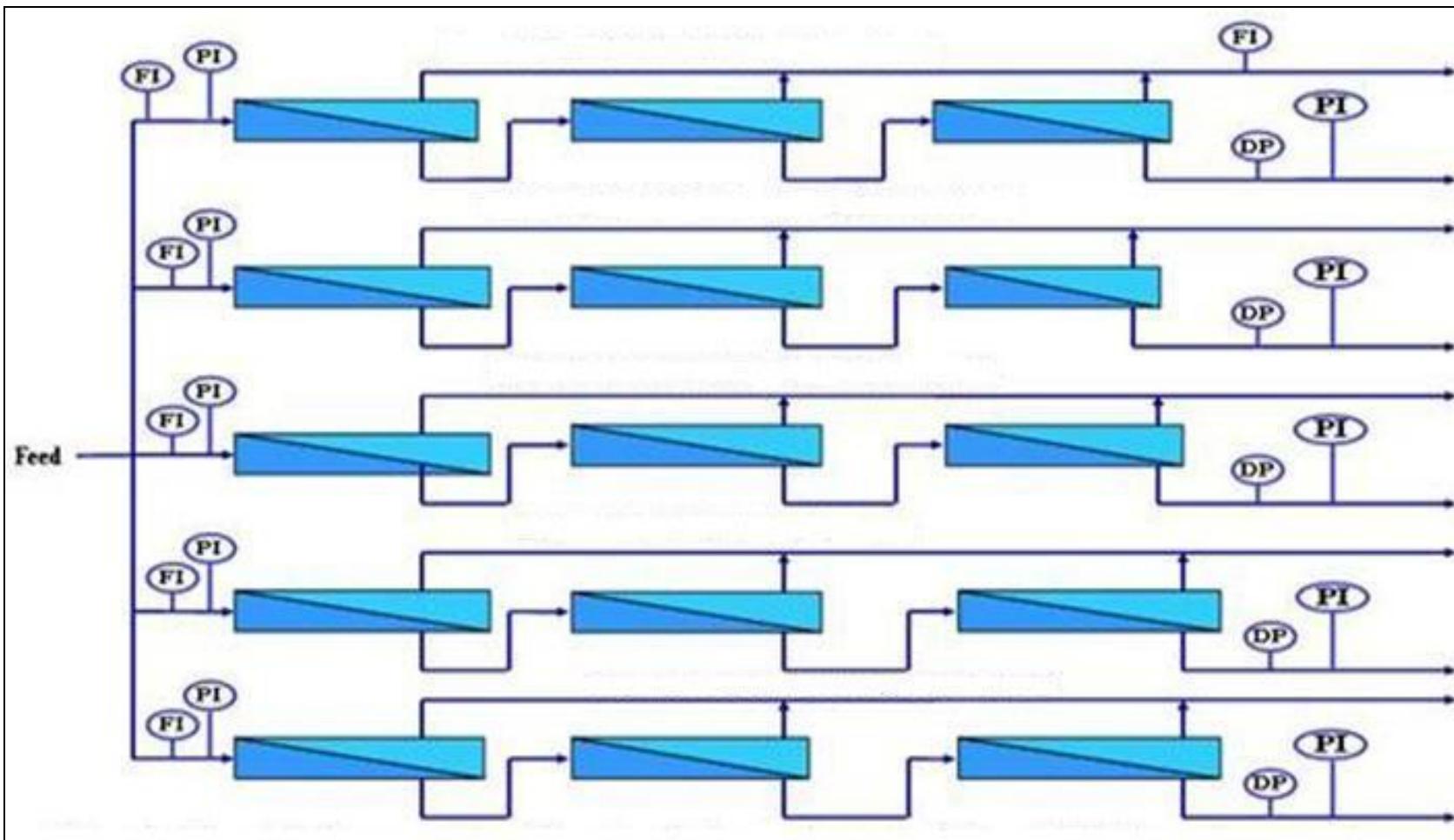
Membrane Details

| Parameter | Membrane | | | | |
|---------------------------------|----------|--------------|------|------|-------|
| Membrane identification code | A | B | C | D1 | D2 |
| Active area (ft ²) | 370 | 300 | 400 | 320 | 400 |
| Max. Flux (m ³ /d) | 24.6 | 19 | 24.6 | 23 | 28.4 |
| Salt Rejection (%) | 99.6 | 99.8 (Cl) | 99.8 | 99.8 | 99.75 |
| Max. operating pressure (bar) | | | 82.7 | | |
| Max. operating temperature (C°) | | | 45 | | |
| Max. Chlorine Conc. (ppm) | | | <0.1 | | |
| Max. feed water SDI | | | 5.0 | | |





Experimental Set-up





Major Issues during the Study

- Not to disturb the plant operation & production
- Lack of control over the operation condition
 - Operation at higher flux and recovery
- Failure to meet maintenance requirement
 - O-ring failures, leaks etc
 - Need to wait for next shut down
- Some membranes operated more time period than other
 - 6,200 hrs to 12,050 hrs



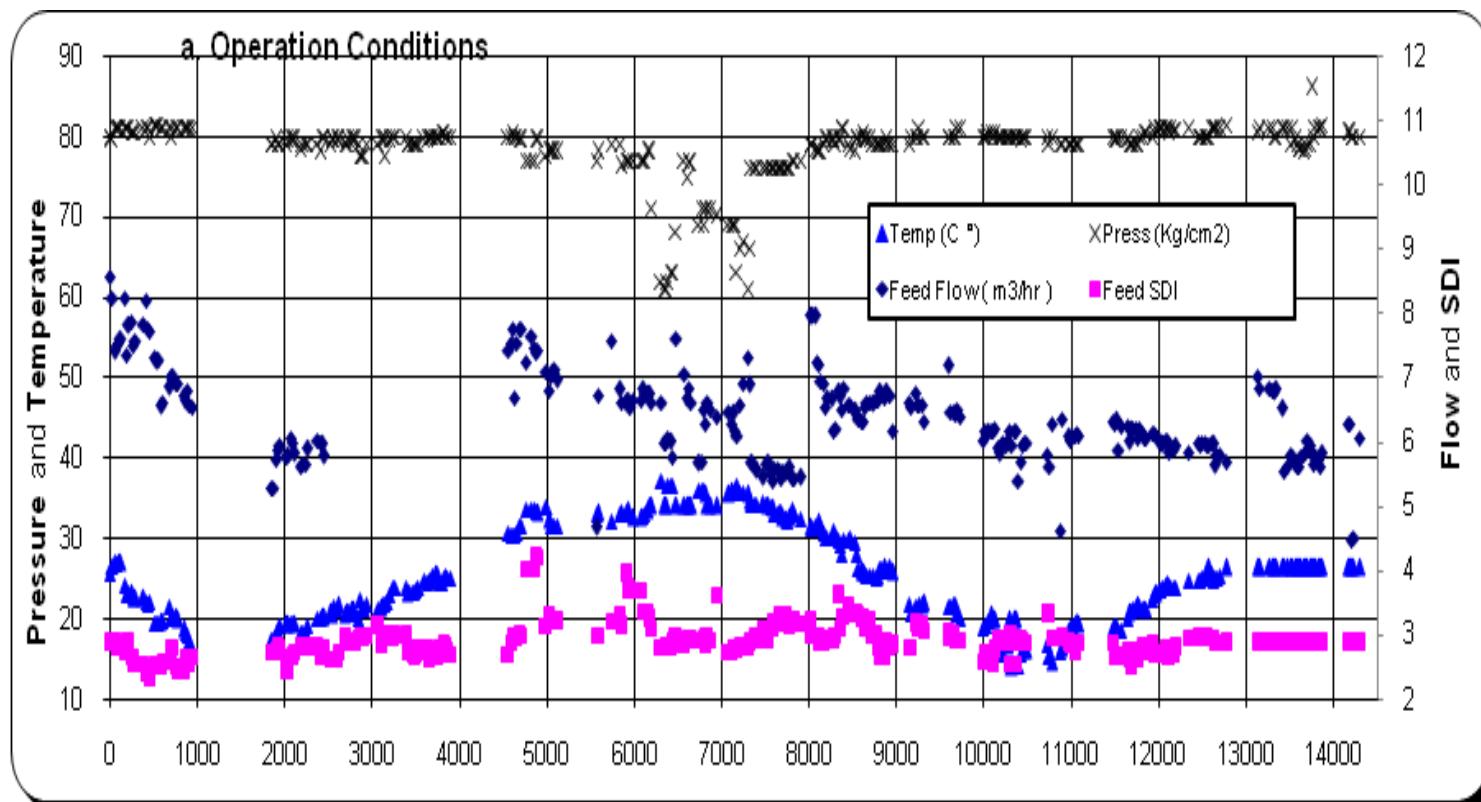


Results



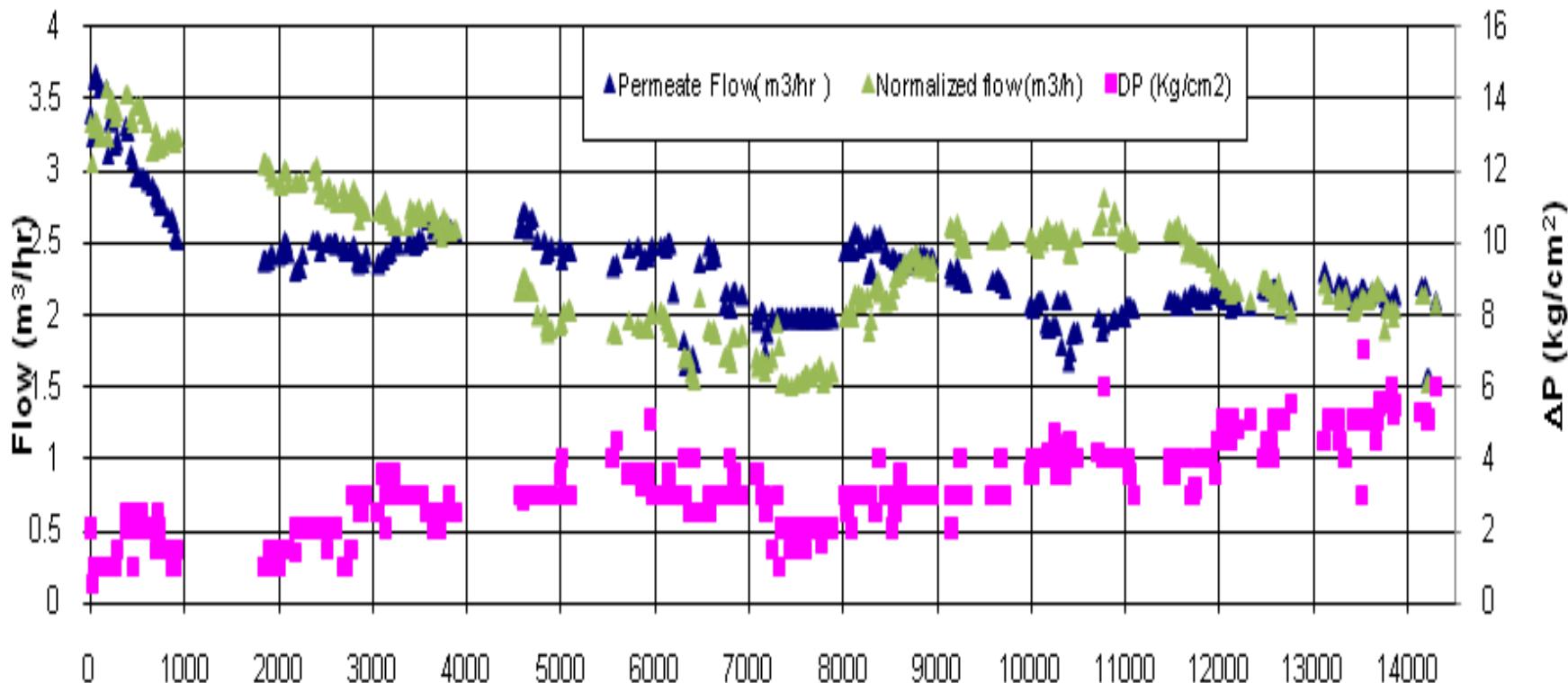
Performance of Membrane A

- Operated 12,000 hrs
- Cleaning at 5,500 hrs



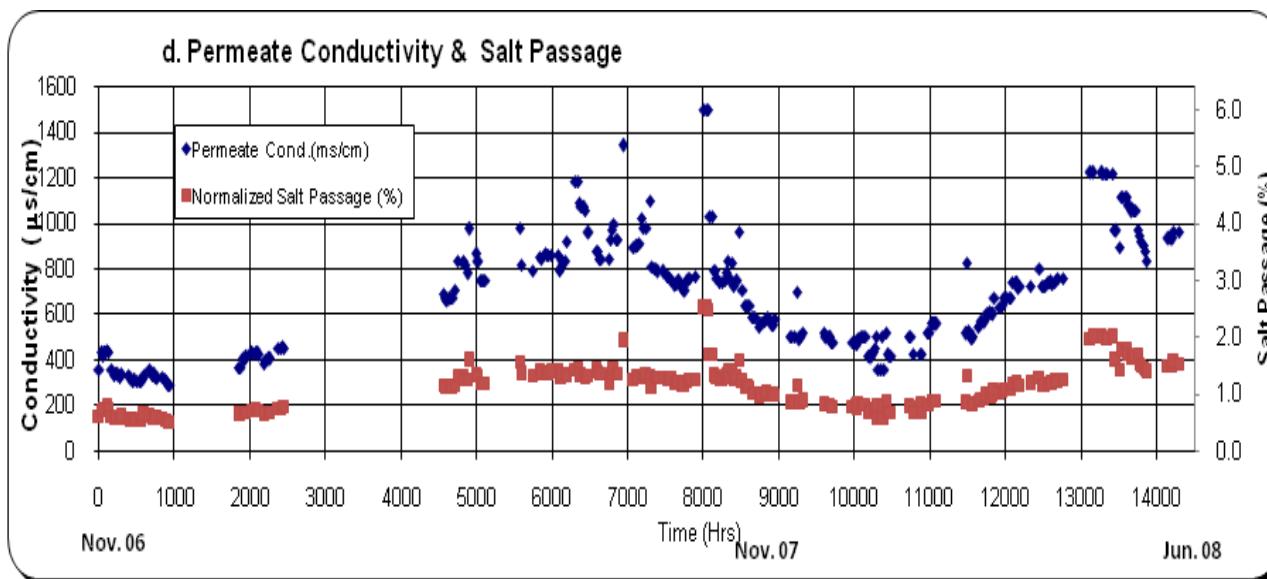
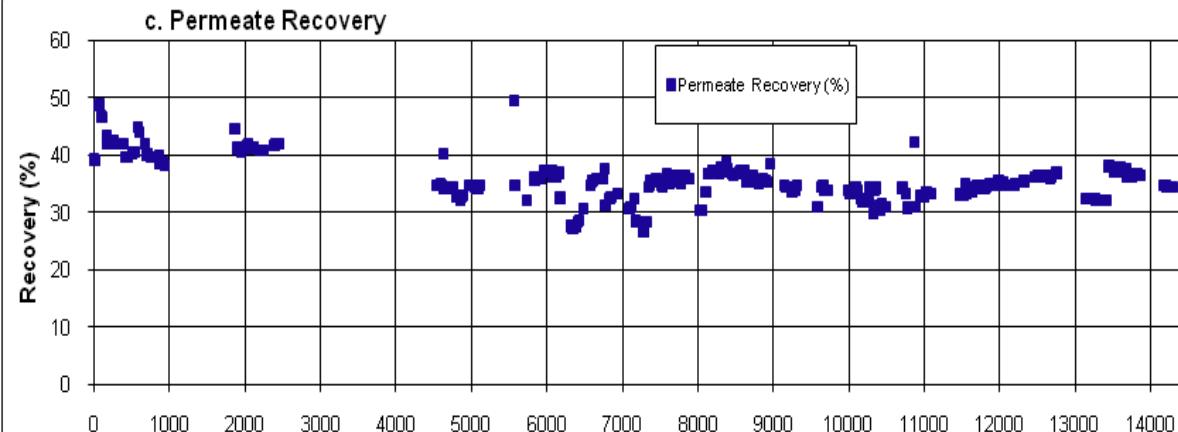
Performance of Membrane A

b. Permeate Flow Rate & ΔP



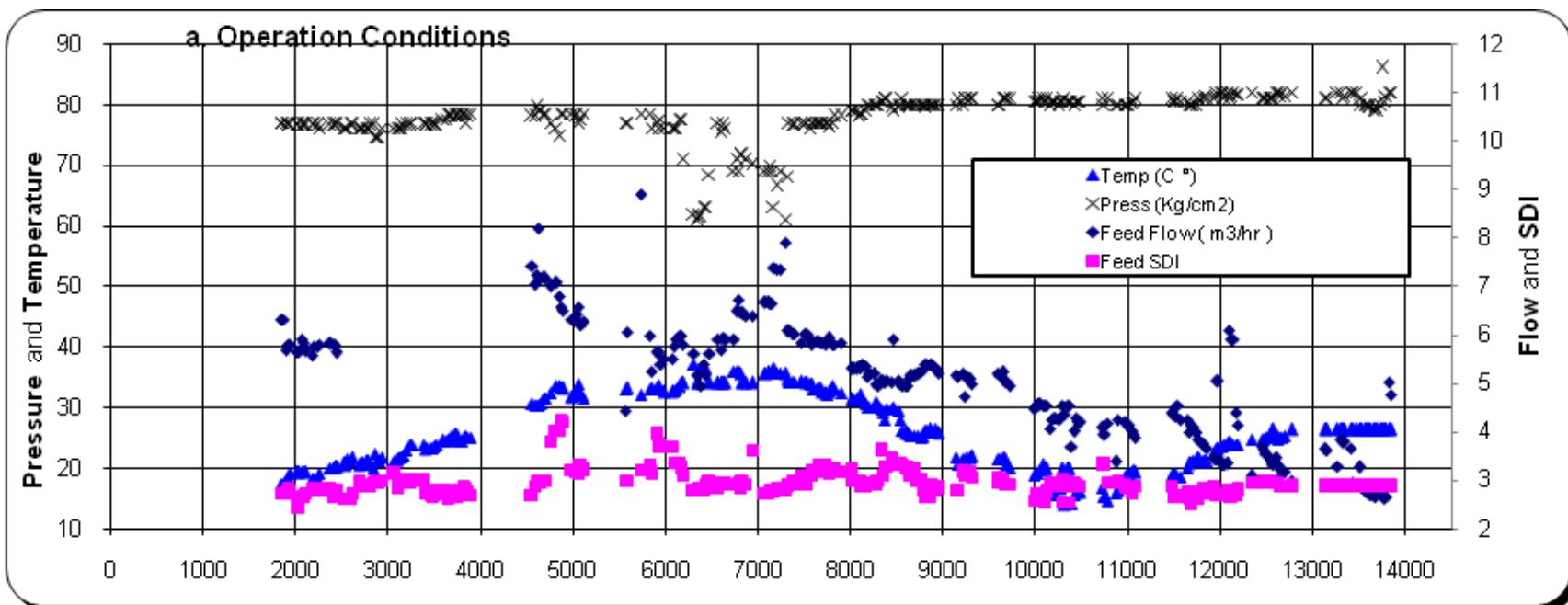


Performance of Membrane A



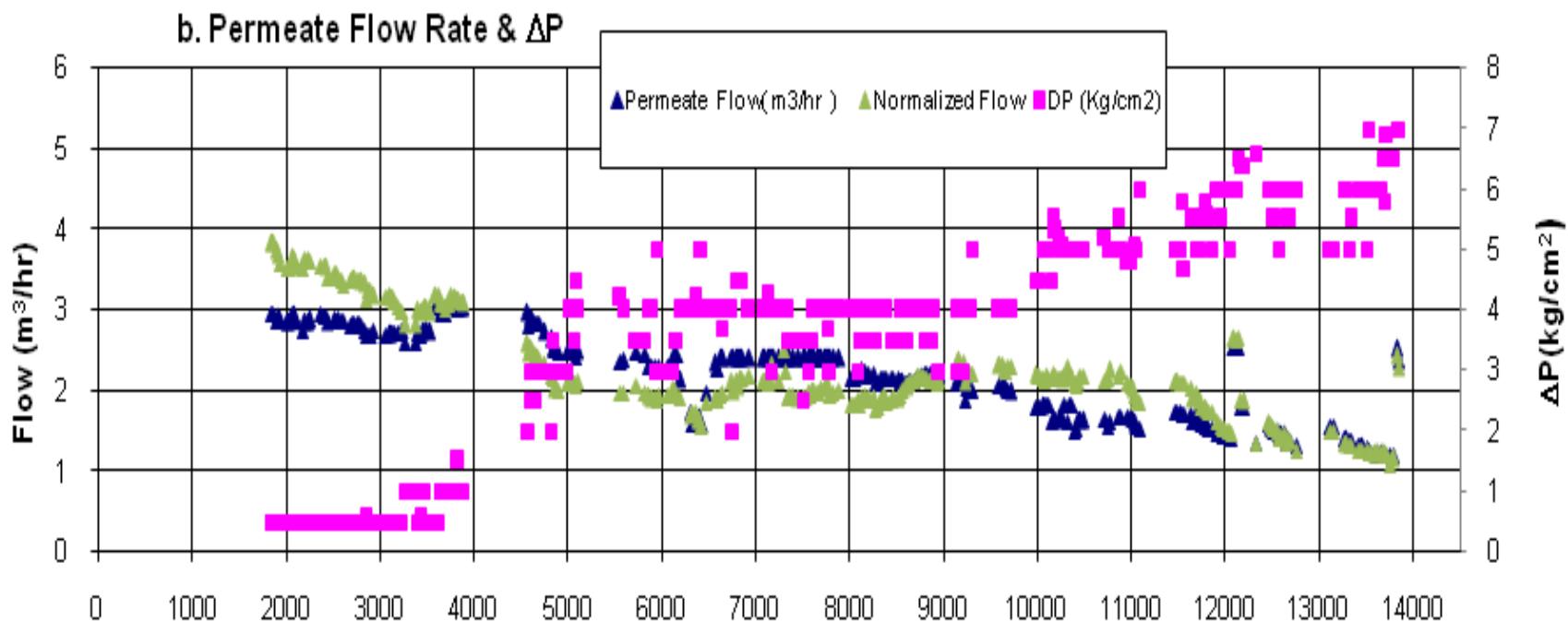
Performance of Membrane B

- Operated 11,000 hrs
- Cleaning at 5,500 hrs





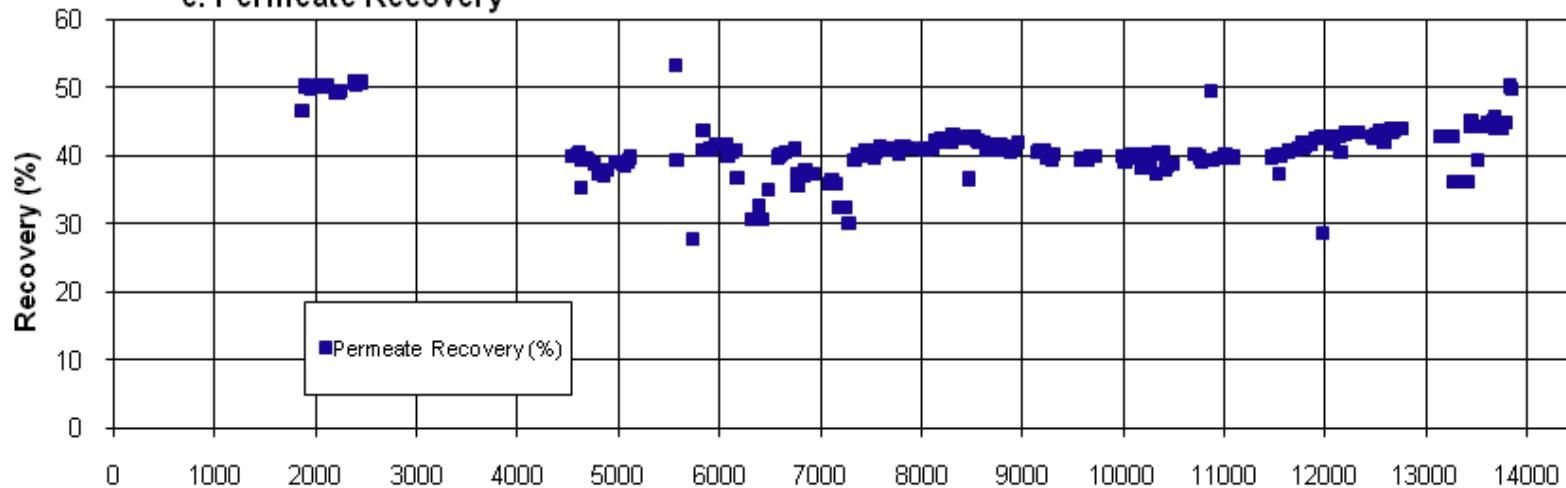
Performance of Membrane B



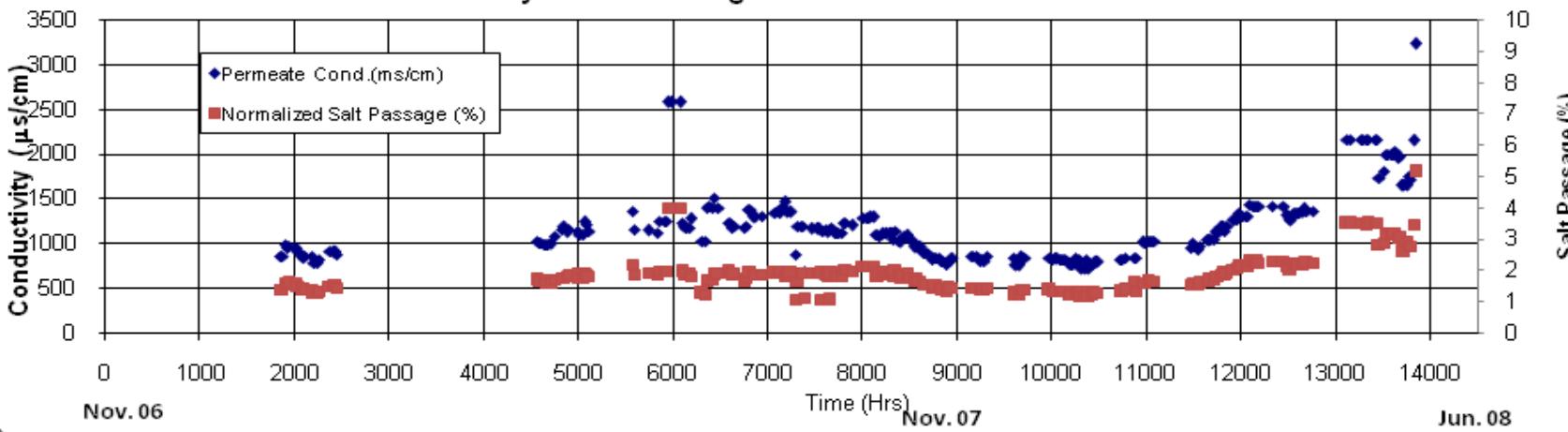


Performance of Membrane B

c. Permeate Recovery

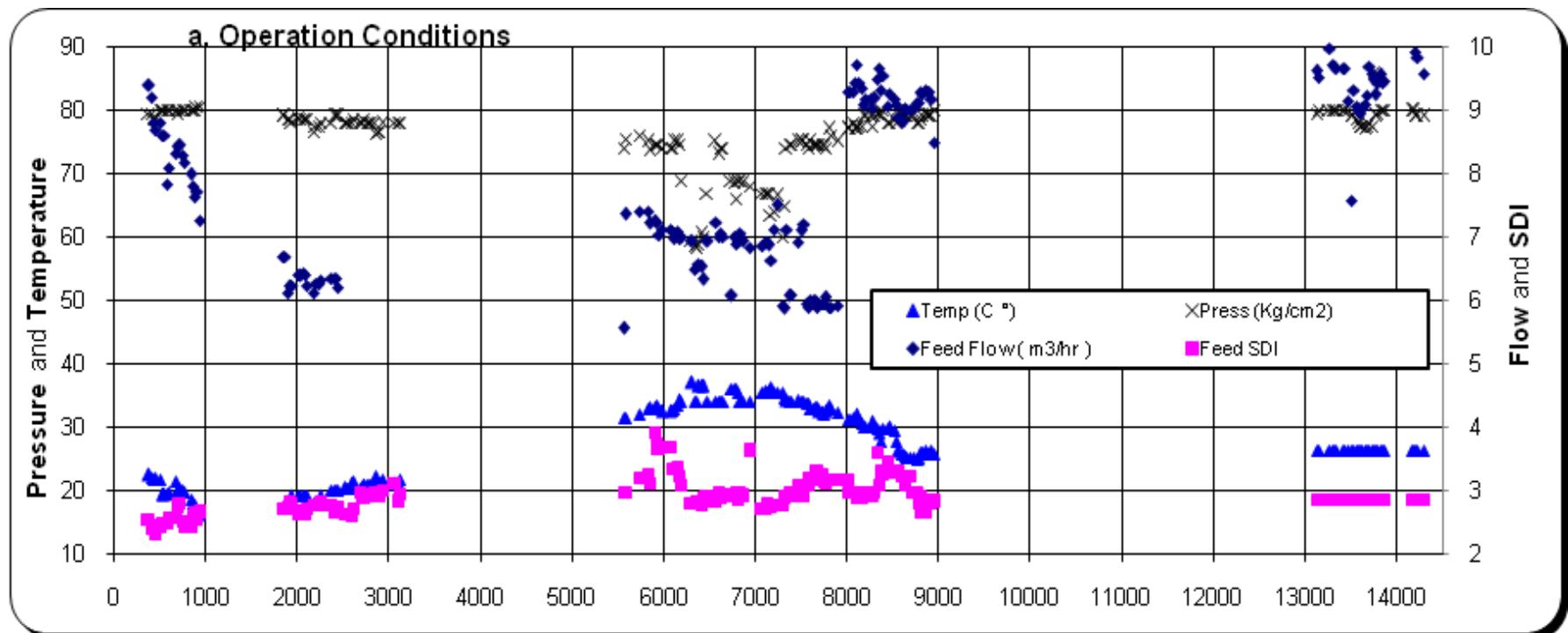


d. Permeate Conductivity & Salt Passage

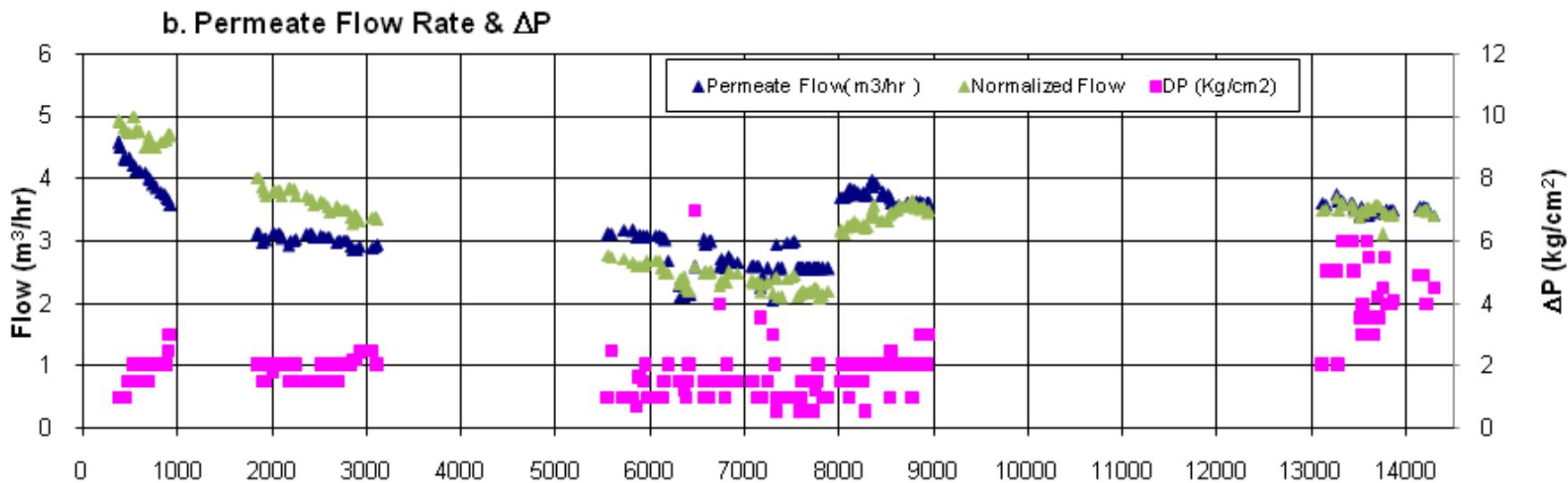


Performance of Membrane C

- Operated 6,200 hrs
- Cleaning 5,500 hrs

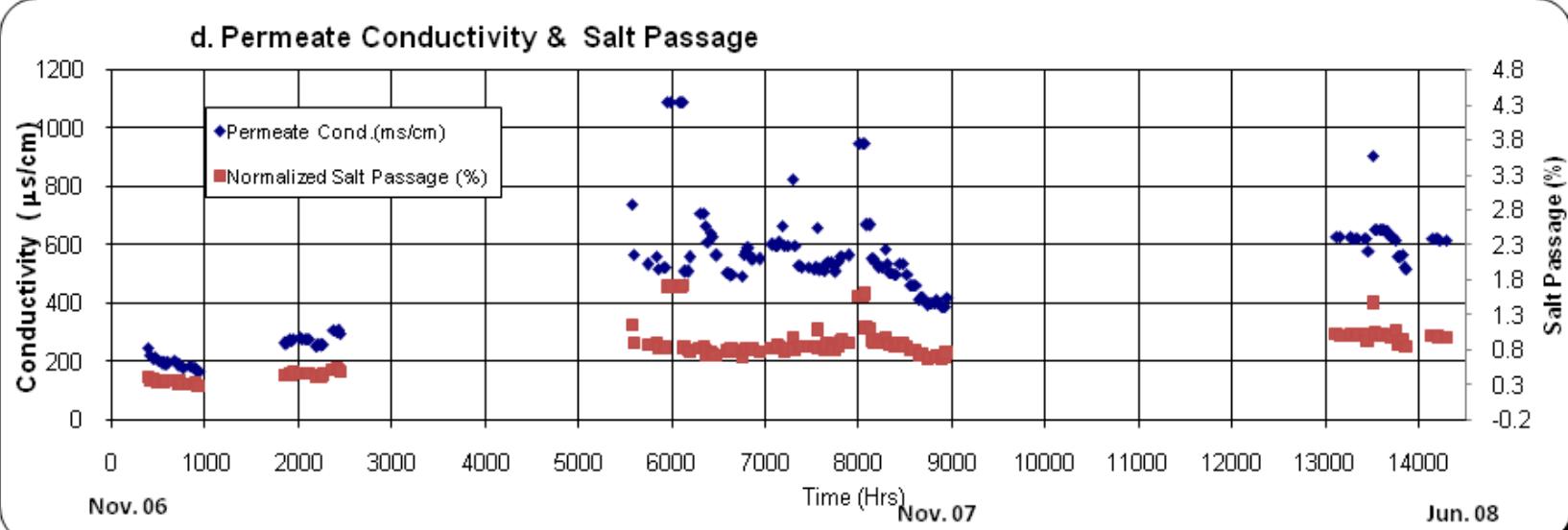
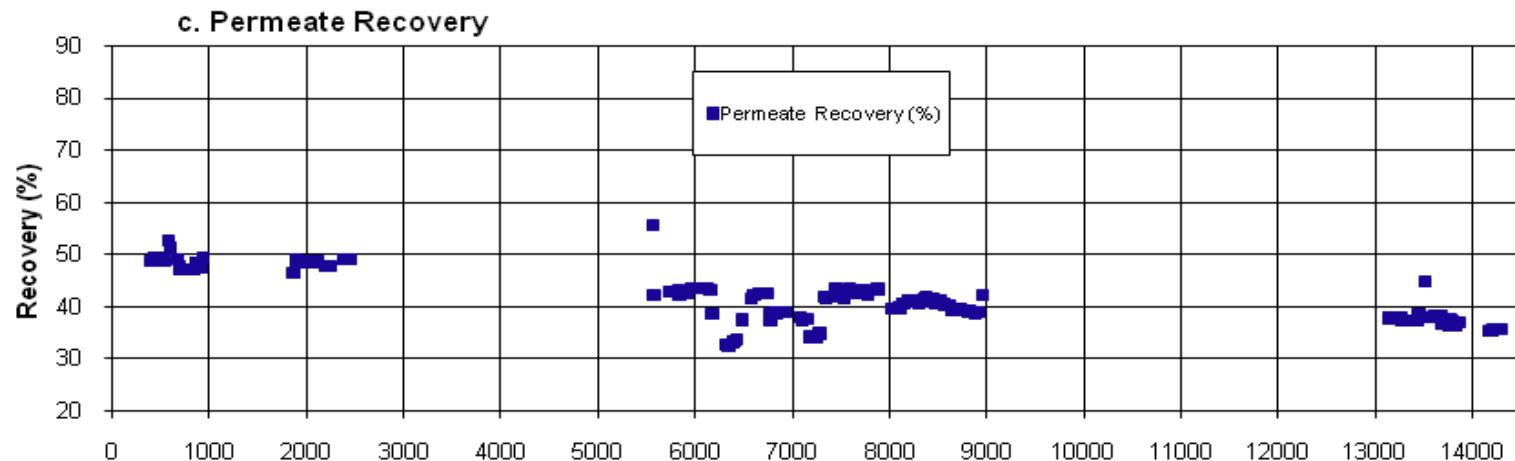


Performance of Membrane C



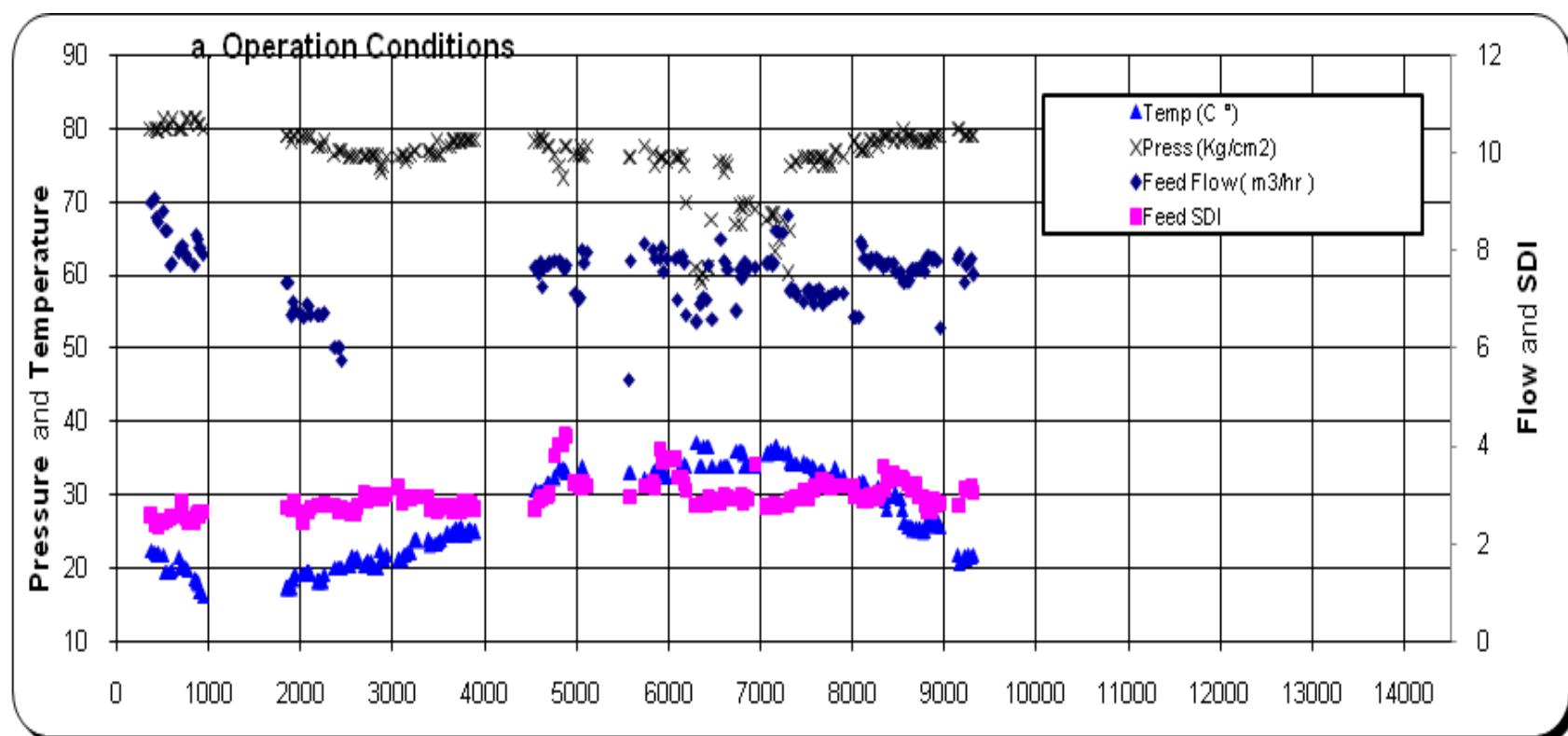


Performance of Membrane C



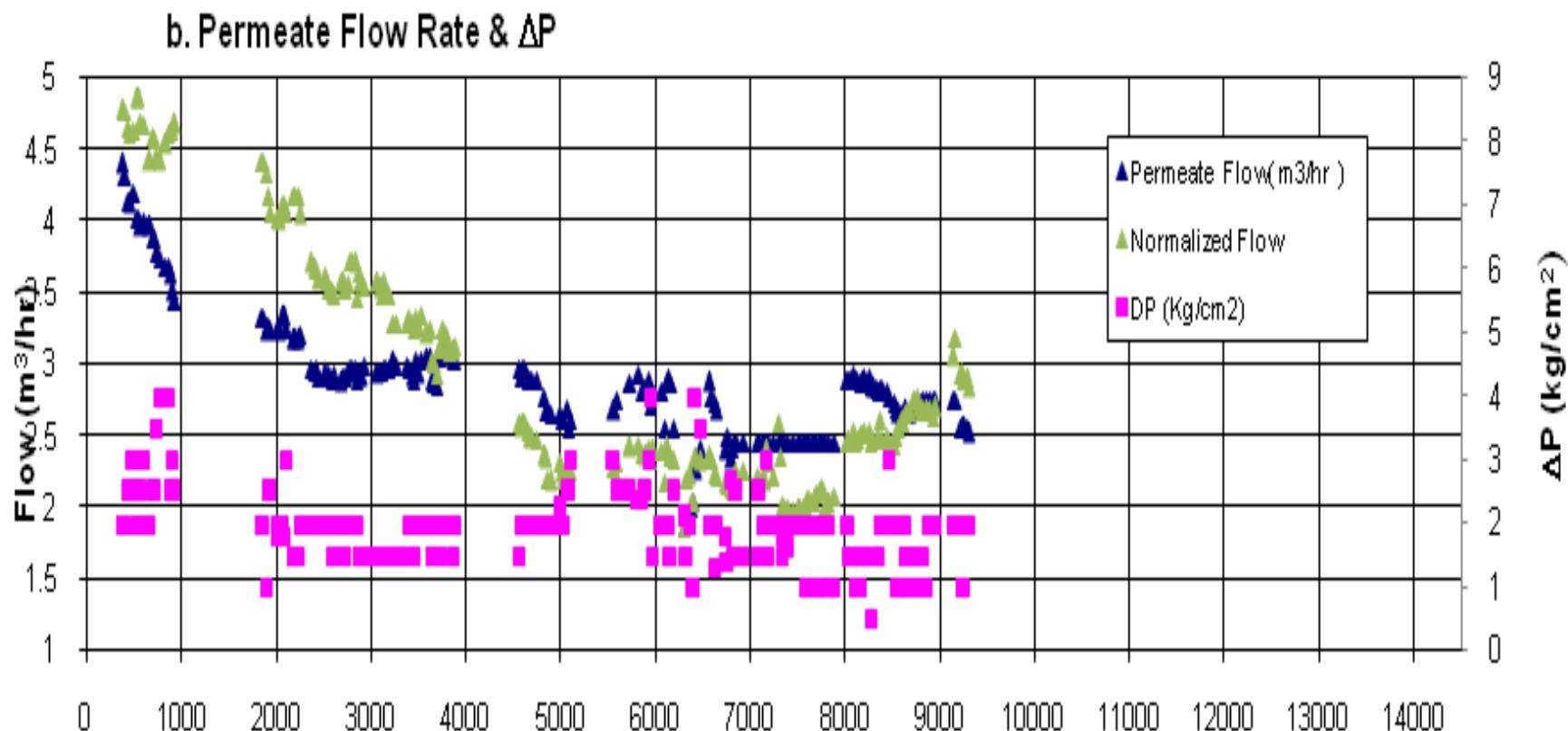
Performance of Membrane D1

- Operated 6,700 hrs
- Cleaning at 5,500 hrs



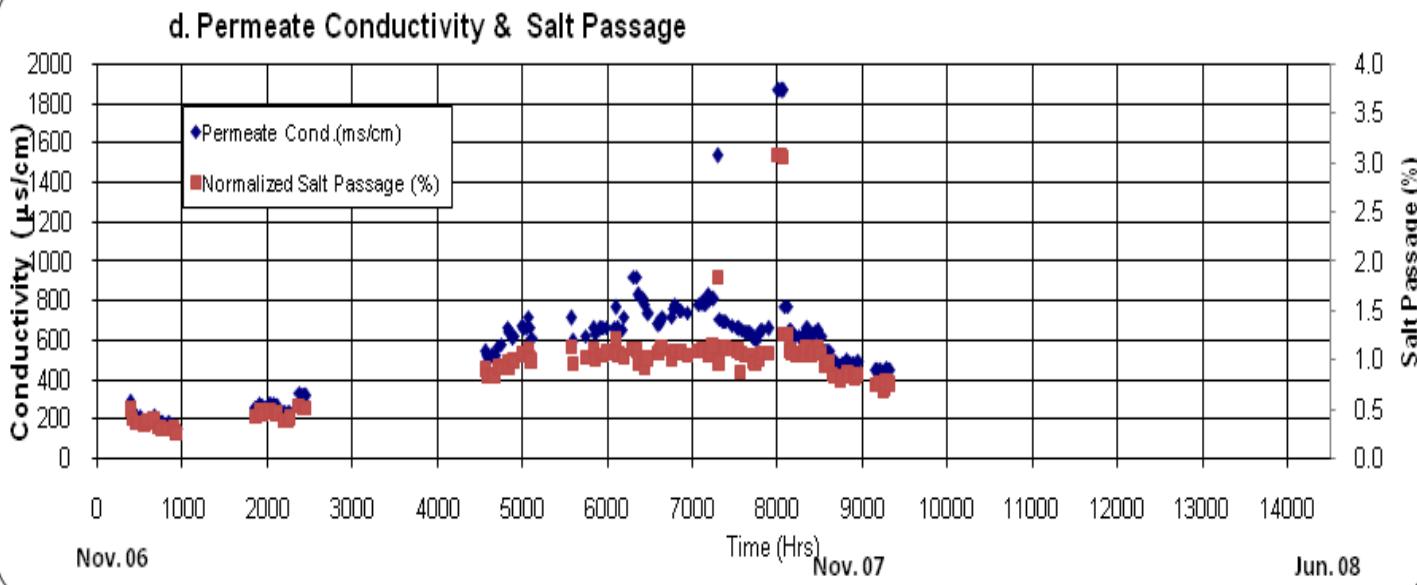
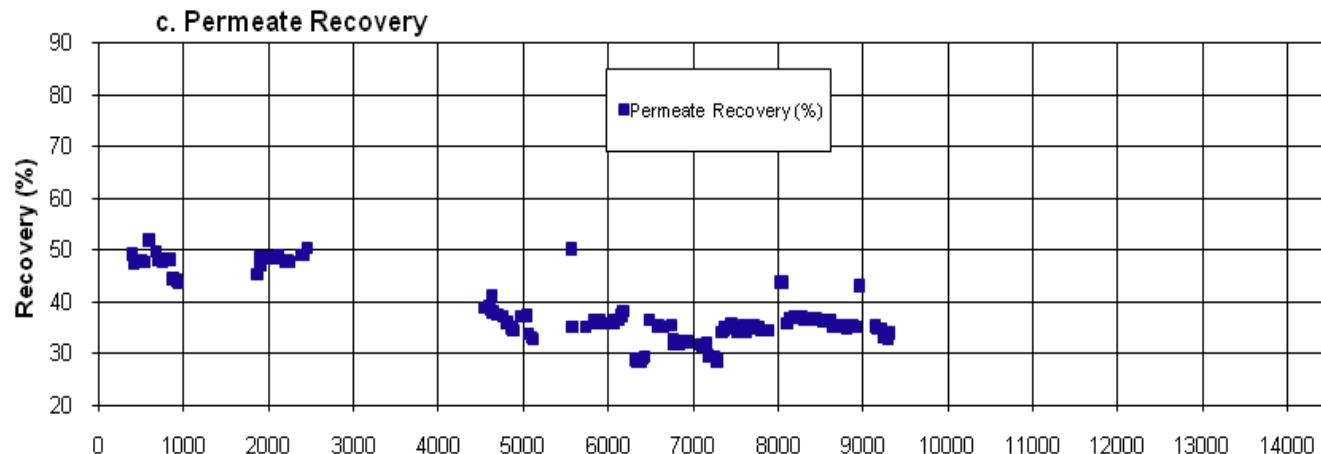


Performance of Membrane D1



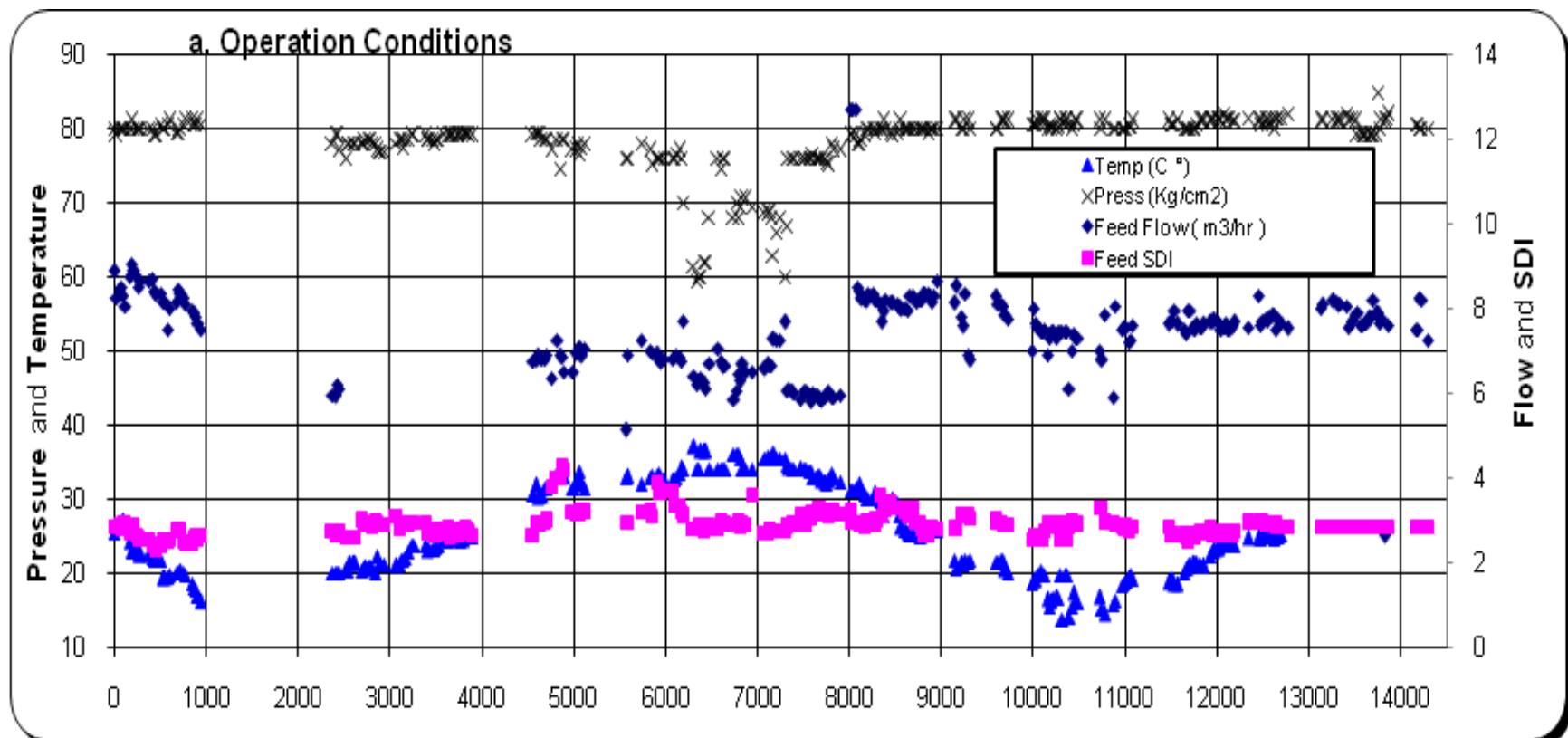


Performance of Membrane D1



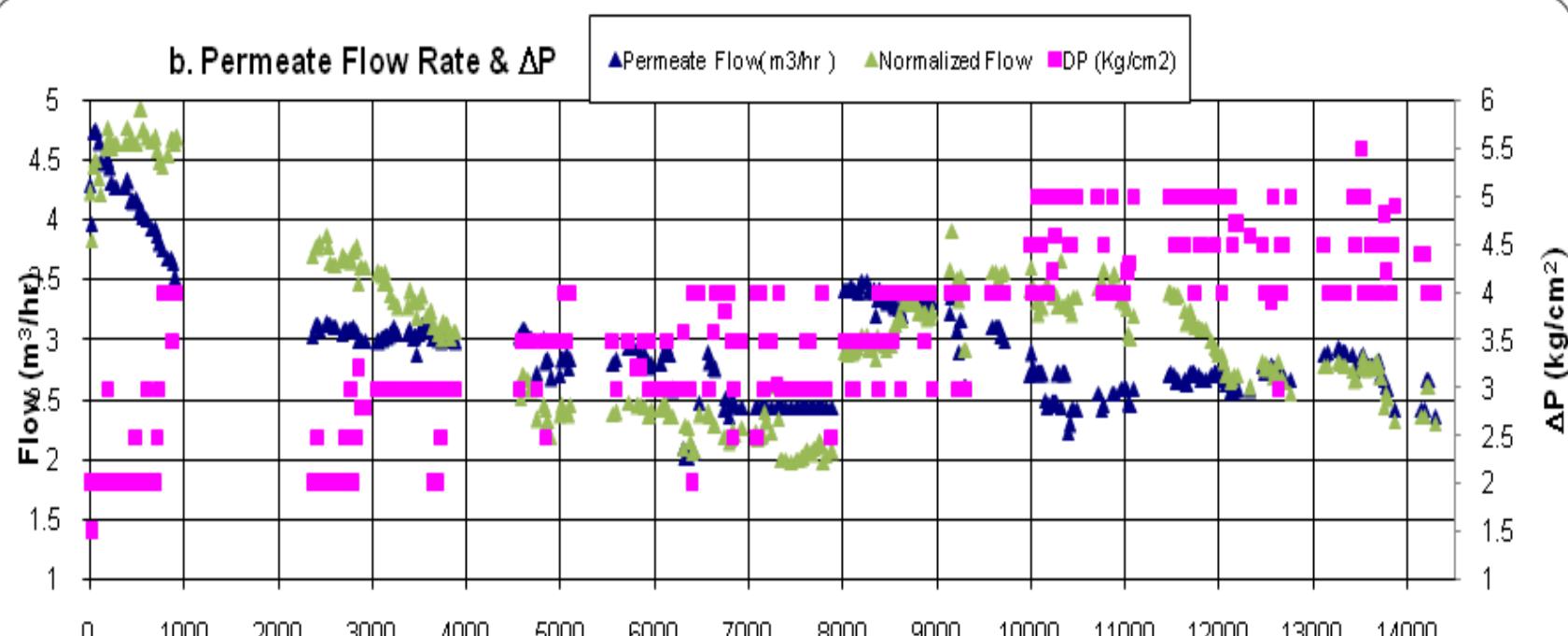
Performance of Membrane D2

- Operated 11,200 hrs
- Cleaning at 5,500 hrs



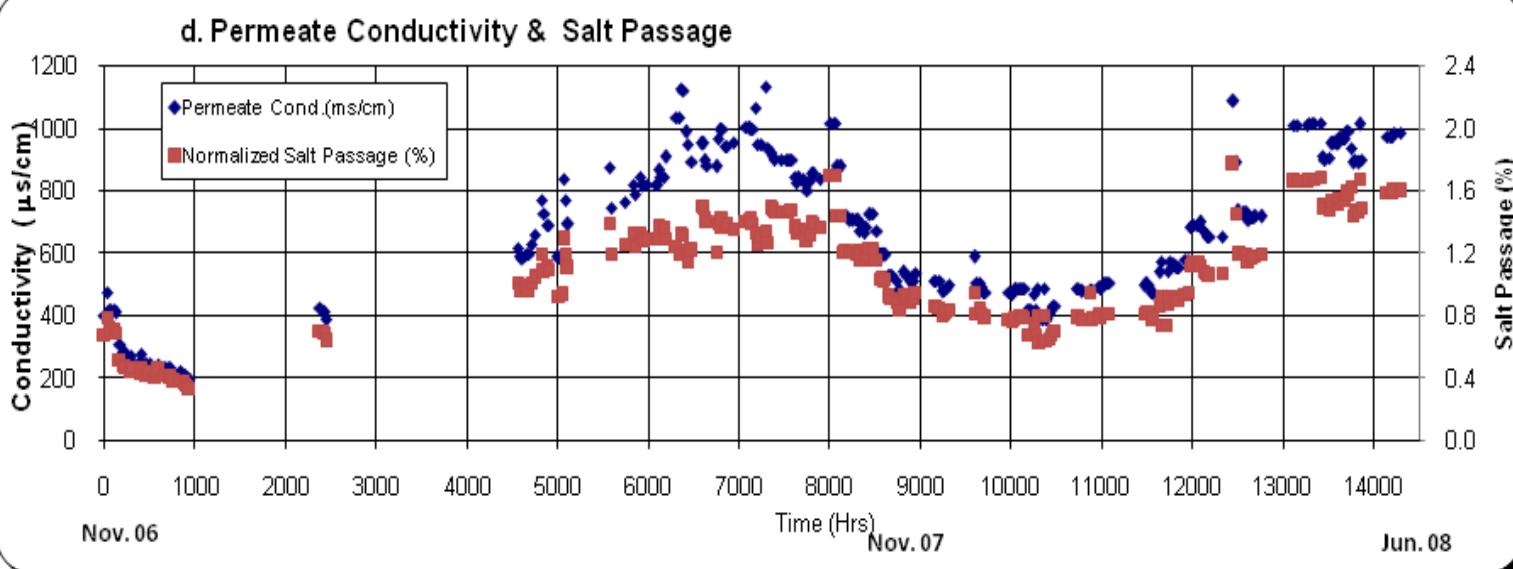
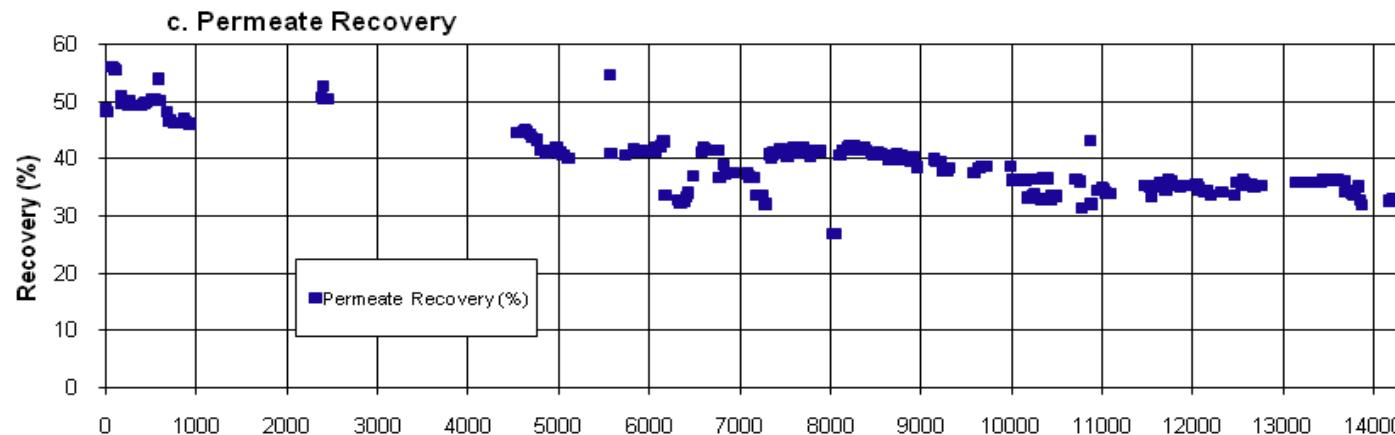


Performance of Membrane D2





Performance of Membrane D2





Concluding Remarks

- Lack of control over operating parameters for individual membranes
- Maintenance work could be performed only during Train shut down
 - some membranes operated only 50% of the time
- These factors made it difficult to have true comparison among the membranes





Concluding Remarks

- To offset the effect of operating time the decline in performance per year was calculated by assuming the reduction in performance is linear





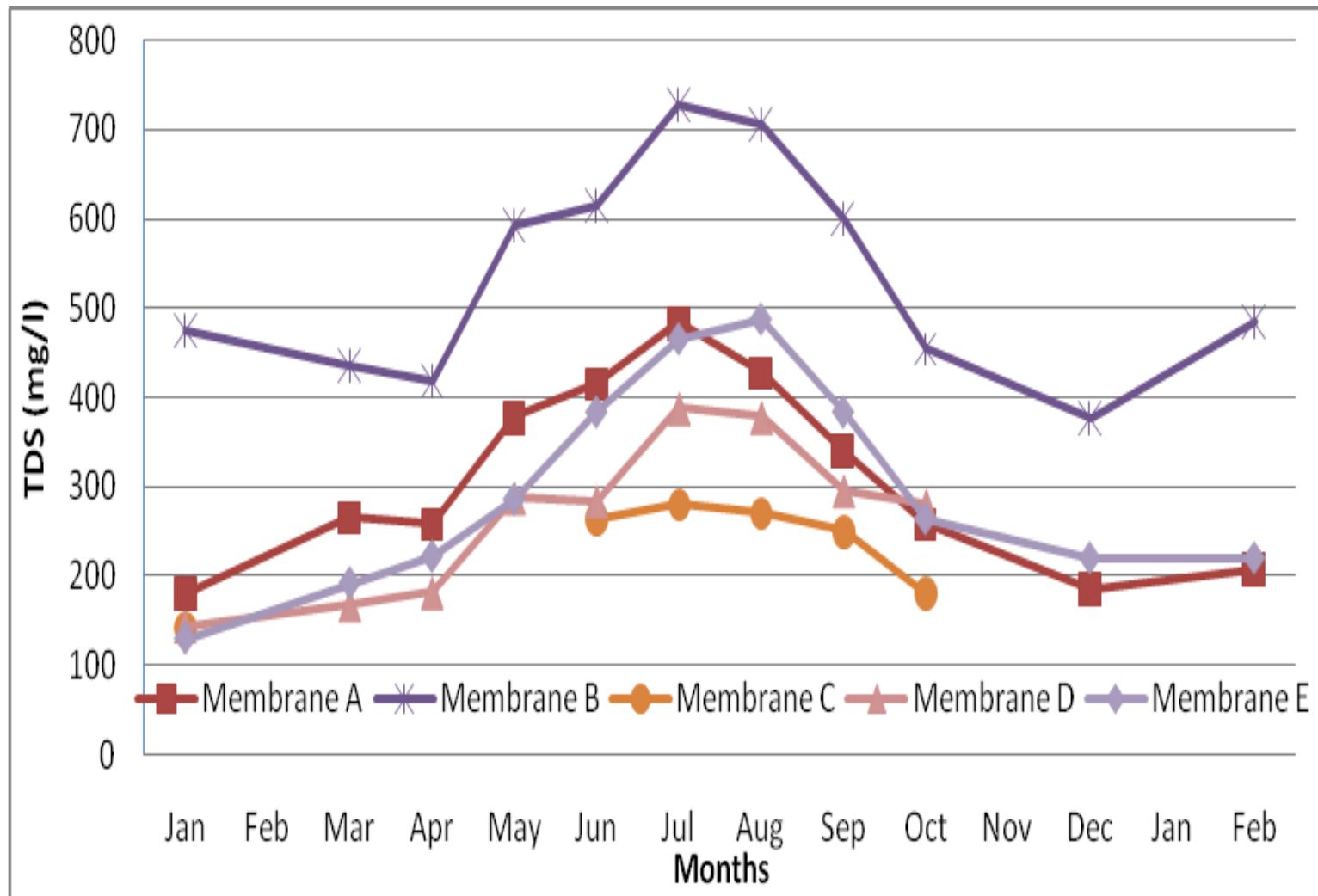
Membrane Performance Comparison

| Membrane → | A | B | C | D1 | D2 |
|--------------------------------------------------------------|-----------------------------|--------|------|-------|-------|
| Net operation hours | 12,054 | 11,094 | 6174 | 6,704 | 11238 |
| Average normalized flow | Initial (m ³ /h) | 3.3 | 3.6 | 4.7 | 4.6 |
| | Final (m ³ /h) | 2.1 | 1.3 | 3.5 | 2.8 |
| | Reduction per year (%) | 26.4 | 50.5 | 36.2 | 51.2 |
| Average Flux (l/m²/h) | 11.21 | 13.0 | 14.6 | 16.2 | 13.3 |
| Average normalized salt passage | Initial (%) | 0.6 | 1.43 | 0.34 | 0.35 |
| | Final (%) | 1.6 | 3.2 | 1.0 | 0.9 |
| | Increase per year (%) | 122 | 99 | 275 | 205 |
| Average differential pressure (ΔP) | Initial (bar) | 1.5 | 0.5 | 1.8 | 2.7 |
| | Final (bar) | 5.1 | 6.0 | 4.4 | 1.7 |
| | Increase per year (%) | 174 | 869 | 205 | -48.4 |





Membrane Permeate Quality Comparison





Concluding Remarks

- Membranes C, D1 and D2 had best productivity, which are more than 30% of that of productivity of Membranes A and B.
- Salt passage results also showed that Membranes C, D1 and D2 are the best performers.
- Membrane A did also showed salt passage very close to this range.
- Membrane B membrane was the worst





Concluding Remarks

- The result of increase in ΔP , which is an indication of fouling resistivity, showed that Membrane D1 was the best performer followed by Membrane D2
- Membranes A and C followed Membranes D1 and D2
- Membrane B was found to be the worst performer among all





Concluding Remarks

- Although, the performance of Membrane A was lower than that of Membranes C, D1 and D2, it has shown to have better ability in maintaining its performance throughout the test period
- This was mainly attributed to its low flux operation compared to other membranes
- On the contrary, Membrane D1 has shown poor ability in maintaining its performance especially the productivity, which was attributed to operation of membrane at higher flux compared to other membranes





Concluding Remarks

- Based on TDS and chloride content in the permeate, the best membranes which can be applied in a single stage SWRO plant are Membrane C followed by Membrane D1
- Membranes D2 and A have acceptable performance
- Of course, one needs to consider the fact that former two membranes operated only 50% of time than that of latter two. If all membranes were operated on same time results may vary





Recommendations

- Although, it is difficult to make precise recommendations due to limitations in the experimental setup, from available data, it could be concluded that Membranes C, D1 and D2 are superior in terms of productivity as well as salt passage.
- Any of these membranes may be used as a replacement to existing membrane, especially Membrane D1 due to its thicker feed spacers (34 mil) that has ability to handle fouling





Recommendations

- Moreover, operation of these membranes at lower flux about 12 l/m²/h may be preferred to maintain the long term membrane performance,
 - require in addition to existing 480 membranes
 - 132 membranes for a membrane with 370 ft² surface area or
 - 86 membranes for a membrane with 400 ft² surface area
- On the other hand, if a higher flux operation is preferred, an efficient chemical cleaning method should be identified which is capable of maintaining long term performance of membranes





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Thank You

