Evaluation of Membrane Technologies for Ex-situ Remediation of Groundwater Impacted with Sulfolane and Several Co-contaminants Including Chloride

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Problem Statement

- Sulfolane is a natural gas sweetening compound designed to remove H_2S, CO_2 and other impurities from the gas stream
- Sulfolane is highly water soluble and has leached into groundwater beneath some sour gas processing facilities in Western Canada
- This research evaluates membrane-based processes for ex-situ treatment of groundwater containing chloride, sodium, total dissolved solids, metals, diisopropanolamine, and sulfolane exceeding regulatory guidelines (AEP 2019)[1]

Problem Statement

- The objective of testing membrane technology is to develop an optimized/efficient process for contaminant removal, energy consumption and operational maintenance

- A remediation trench was previously used at the subject site to mitigate the environmental impact, but is currently suspended; there is no current on-site treatment or disposal system, so all impacted water would need to be trucked off-site to a disposal well

Objectives and Goals

- The main contaminants of concern were **sulfolane** and **chloride (TDS)**
- Applying membrane technology promotes water reuse, returning it back into the hydrologic cycle
- The treated wastewater is intended to be used for groundwater recirculation

Why Water Treatment

[2]

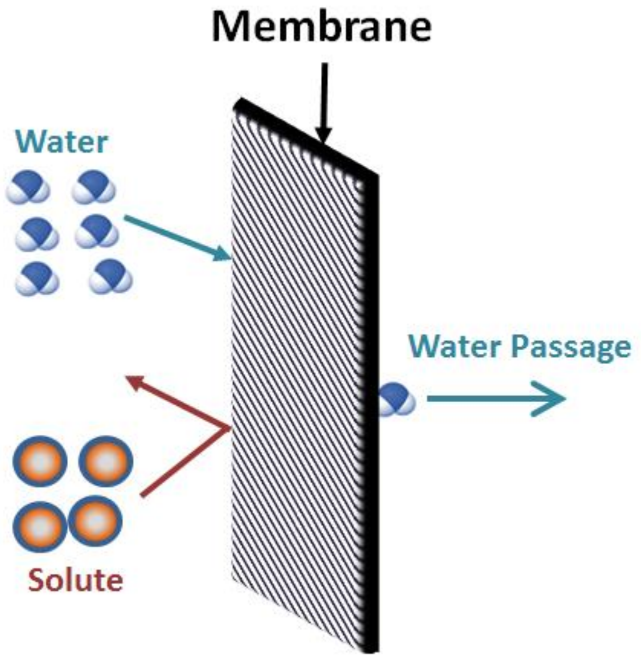
[3]

Physical treatment

Chemical treatment

Biological treatment

Membrane technology



Advantages:

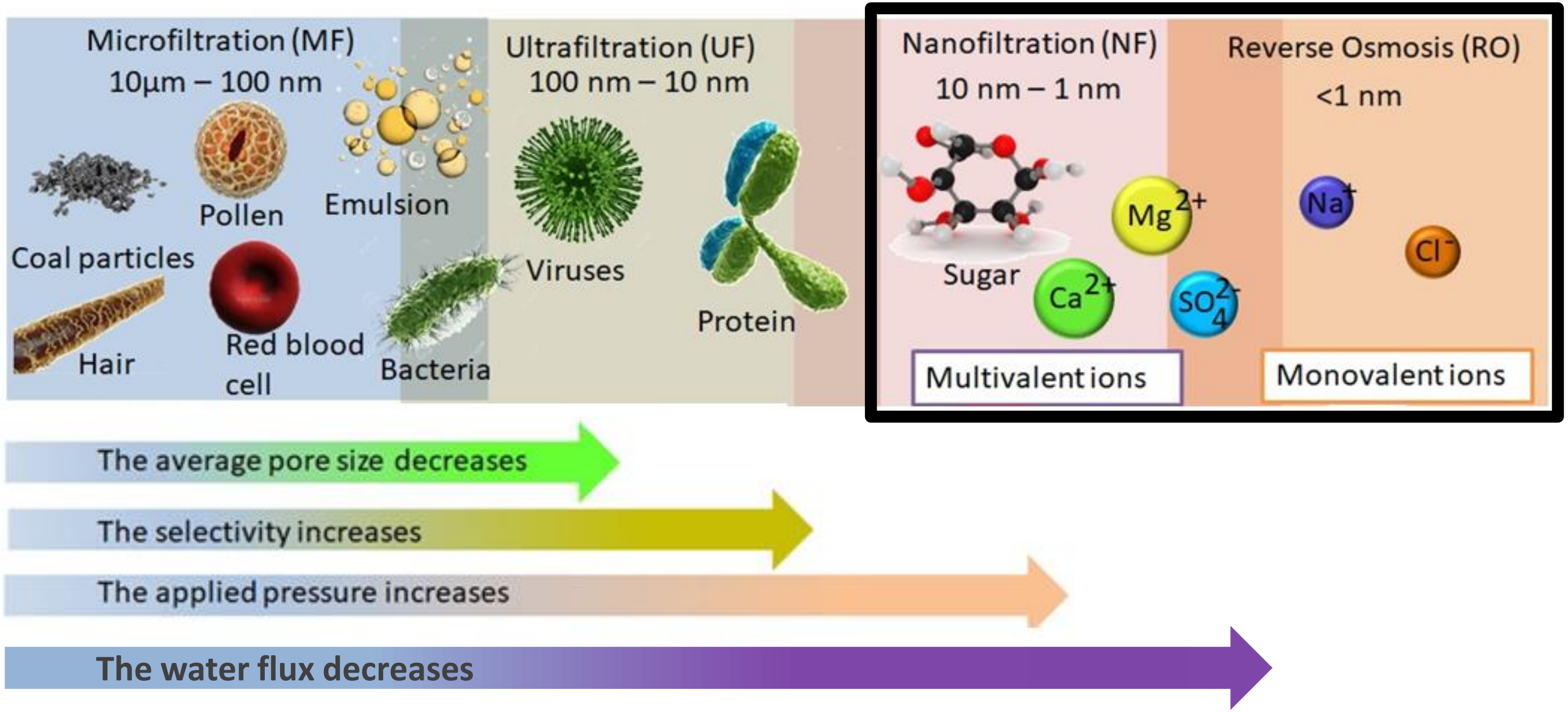
- High product quality
- Easily integrated in current treatment units
- Small footprint

Challenges:

- High operation energy
- Membrane fouling

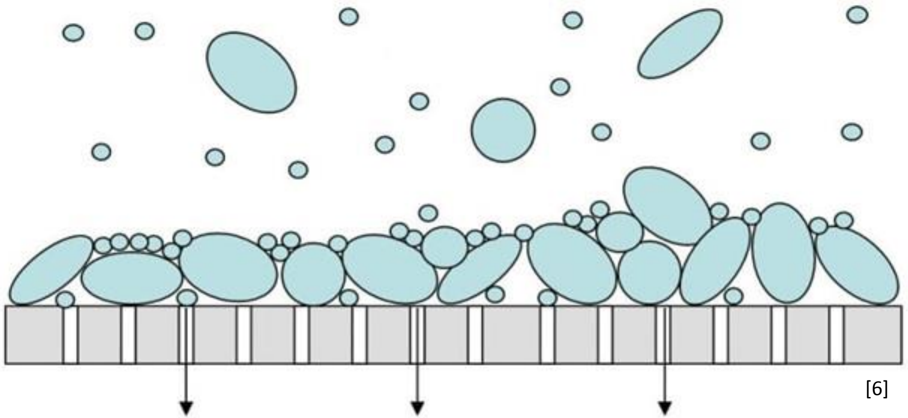
[4]

Membrane Processes



Membrane Fouling

- Fouling is the deposition of contaminants on the membrane
- Reduces the efficiency of process by decreasing the permeate water flux [5]



[6]

Materials and Methods

- Initial tests used synthesized trench water
- Later tests used two different bulk samples of site trench water (Summer 2018 and Spring 2019)
- All tests were conducted in a temperature controlled environment (7^{o}C)
- Sulfolane concentration was spiked to be present in the range from 17 to 34 mg/L for bench tests

Materials and Methods

- Total dissolved solids (TDS) removal was estimated from conductivity monitoring results
- Hardness concentration was measured with a hardness analyzer
- Concentration of sulfolane was analyzed by Bureau Veritas (BV) Laboratory.
- All of the metal ions were analyzed using inductively coupled plasma (ICP) analysis
- Anions were analyzed by ion chromatography

Characterization of trench water

Dissolved Parameter	Unit	Summer 2018 Bulk Trench Sample	Average Trench Water – Fall 2010 Monitoring Data	Groundwater Guideline[1]
Conductivity	µS/cm	1220	3466	Not Specified
TDS	mg/L	780[a]	2800	500
pH		7.1	7.6[b]	6.5-8.5
Mg	mg/L	37	61	Not Specified
Ca	mg/L	170	317	Not Specified
Na	mg/L	193	337	200
Cl	mg/L	500	913	120
NO_3-N	mg/L	1.4	0.043[b]	3
Ba	mg/L	1.81	3.57	1
Si	mg/L	8.95	6.93	Not Specified
Sulfolane	mg/L	3.6[c]	16.4	0.09

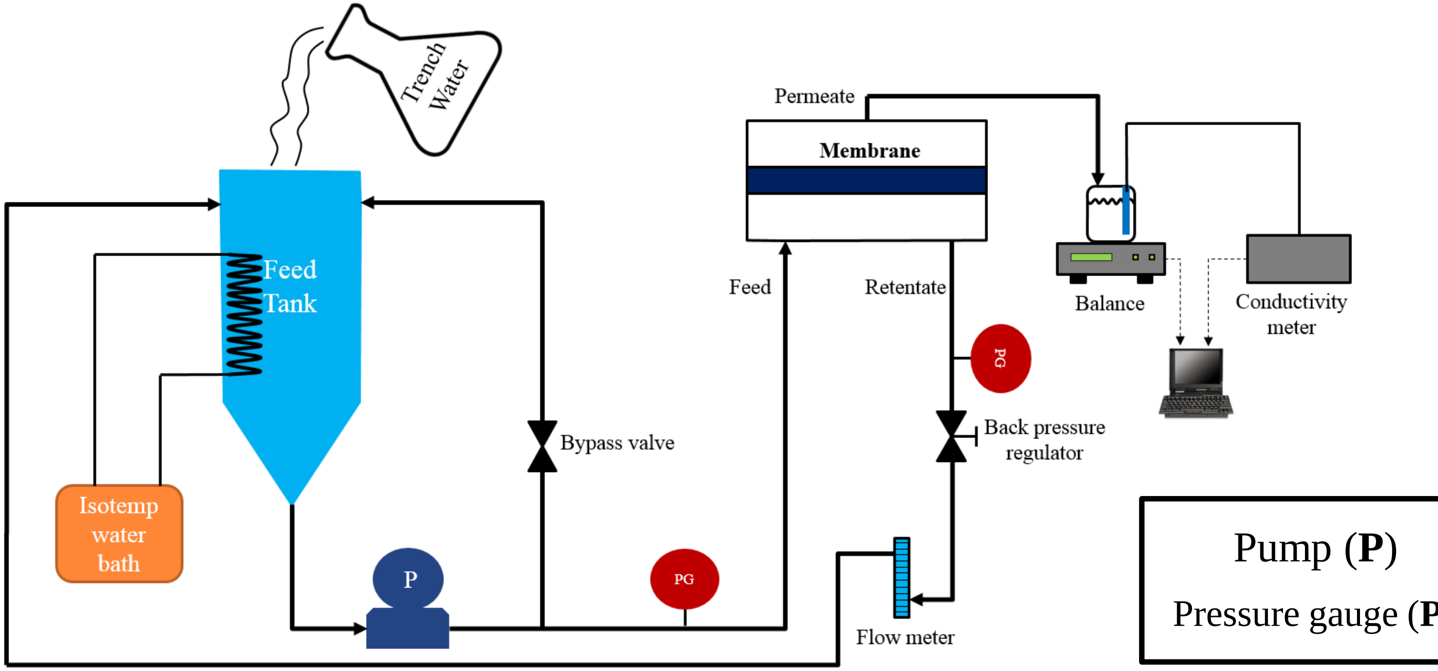
[a]Estimated from conductivity[7].
[b]Where no 2010 results available, historical average listed.
[c]Sulfolane concentration was depleted in storage thus for all experiments sulfolane was spiked to a concentration range of 17 to 34 mg/L.

Design of Experiment: Part 1

Initial tests using a synthesized trench water:

- Testing nanofiltration (NF90) and reverse osmosis (BW30 & SUEZ) commercial membranes
- Studying the water flux and fouling behavior of the filtrations
- Analyzing the contaminant removal rate of the commercial membranes

Membrane Bench Test (Cross-Flow Filtration)

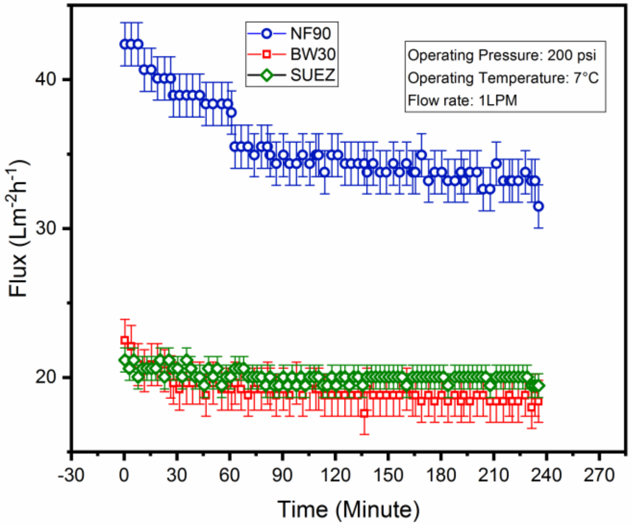


Pump (**P**)

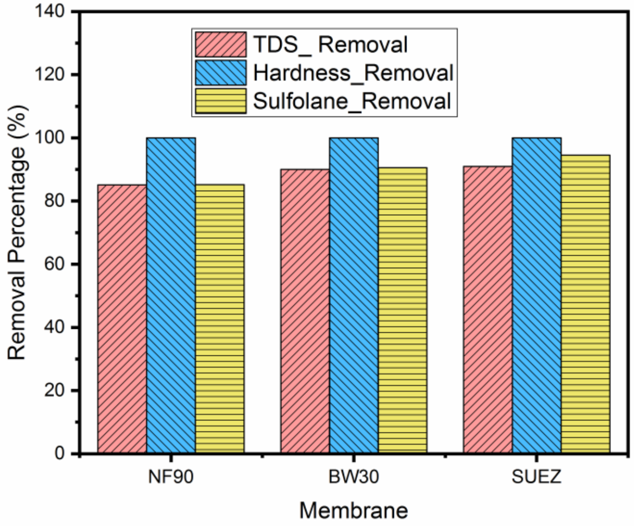
Pressure gauge (**PG**)

Synthesized Trench Water Filtration

Water flux trend



Removal of contaminants

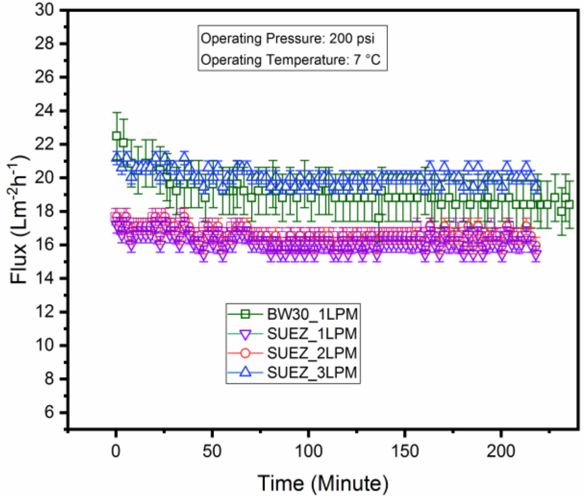


Guideline requirement for Sulfolane: 0.09 mg/L

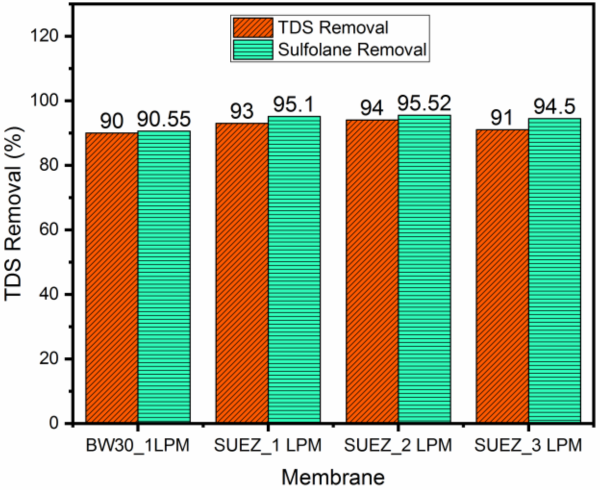
Parameter	Treated water by NF90	Treated water by BW30	Treated water by SUEZ
Sulfolane concentration of feed water	32 mg/L	18 mg/L	20 mg/L
Sulfolane concentration of permeate (treated) water	4.7 mg/L	1.7 mg/L	0.99 mg/L

Effect of flowrate

Water flux trend



Removal of contaminants

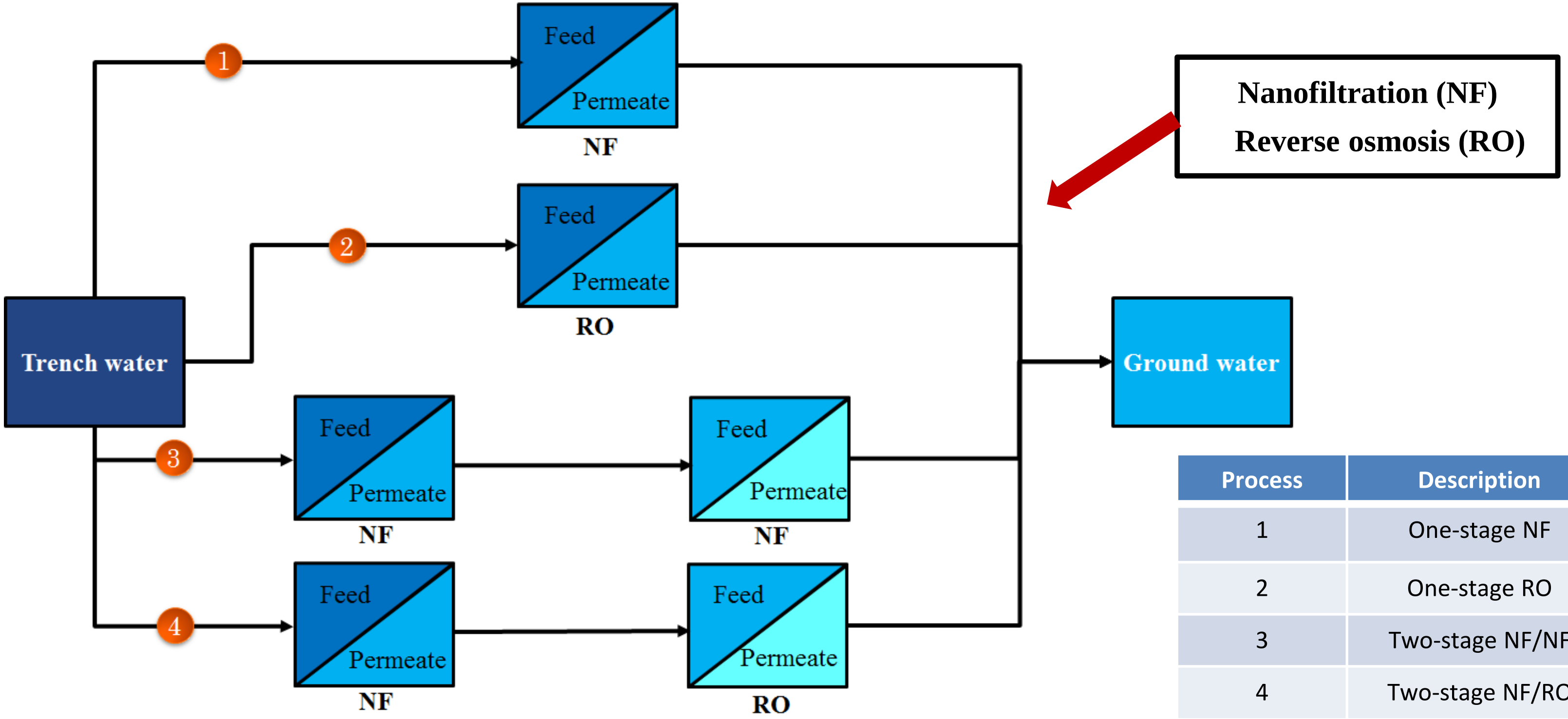


Parameter	BW30_1LPM	SUEZ_1LPM	SUEZ_2LPM	SUEZ_3LPM
Sulfolane concentration of feed water	18 mg/L	20 mg/L	34 mg/L	20 mg/L
Sulfolane concentration of permeate (treated) water	1.7 mg/L	0.99 mg/L	1.52 mg/L	1.1 mg/L

Summary of initial results

- The SUEZ (RO) membrane showed the highest sulfolane removal rate
- Increasing the flow rate could potentially increase the contaminant removal
- The one-stage membrane processes could not bring down the sulfolane concentration to the desired level

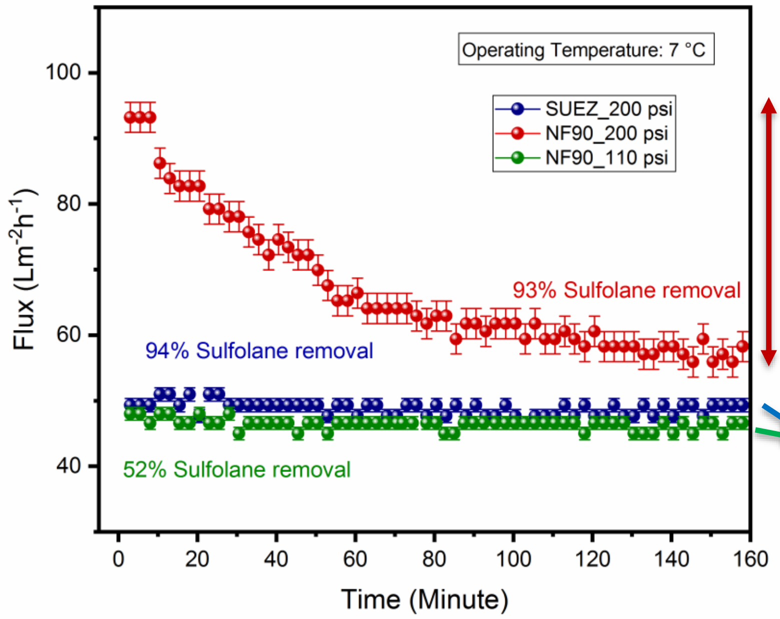
Design of Experiment: Part 2 – bulk trench water



Process	Description
1	One-stage NF
2	One-stage RO
3	Two-stage NF/NF
4	Two-stage NF/RO

One-stage filtrations of bulk trench water

Water flux trend

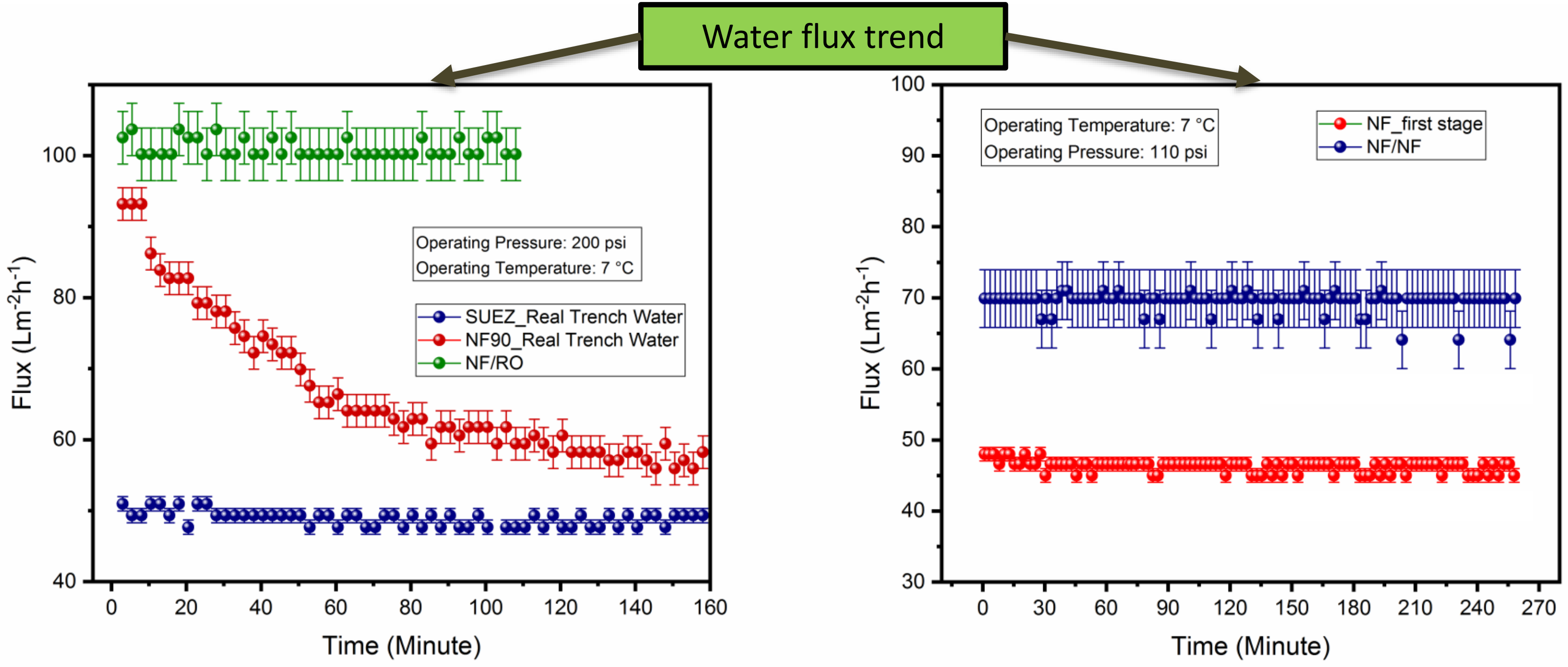


Flux decline

Constant flux

No fouling at 110 psi for the filtration with NF90

Two-stage filtrations of bulk trench water



Properties of treated water samples

Parameter	Unit	Summer 2018 bulk trench sample	NF Permeate	RO Permeate	NF/NF Permeate	NF/RO Permeate	Groundwater Guideline[1]
Conductivity	µS/cm	1220	109	36	13	31	Not Specified
TDS	mg/L	780[a]	70[a]	23[a]	8.3[a]	20[a]	500
Ca	mg/L	170	0.94	0.75	0.70	0.63	Not Specified
Mg	mg/L	37	0.23	0.20	0.10	0.02	Not Specified
Na	mg/L	193	11.1	5.5	2.2	0.81	200
Cl	mg/L	500	35	25	20	7.0	120
NO_3-N	mg/L	1.4	0.0	0.0	0.0	0.0	3
Ba	mg/L	1.81	0.007	0.006	0.004	0.004	1
Si	mg/L	8.95	0.070	0.150	0.000	0.000	Not Specified
Sulfolane	mg/L	17 to 34[b]	0.570	0.490	2.20	0.063	0.09

[a]Estimated from conductivity[7].
[b]Sulfolane concentration was depleted in storage thus for all experiments sulfolane was spiked to a concentration range of 17 to 34 mg/L.

Conclusions of Bench Study

- The two stage NF-RO could provide a high quality water for groundwater recirculation
- The recommended operating pressure for NF90 is 110 psi to avoid fouling
- Increasing the flow rate of the feed water can improve the contaminant removal rate
- All of the pressure driven NF and RO tests were efficient in removing chloride and metal ions

Preliminary Cost Analysis

No Treatment and Disposal	• $14,000,000
Membrane Treatment and Disposal of Concentrate	• $9,500,000
Overburden Soil Excavation	• $2,500,000

Recommendation and Future work

- Other commercial membranes could be tested for the treatment of this wastewater

- Potential to develop a hybrid process using membrane separation as a pre-treatment, and to address inorganic impacts, followed by conventional treatment of residual sulfolane (biological or chemical)

- An on-site pilot study could be conducted to optimize process and further evaluate costs and benefits prior to moving to a full scale system

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