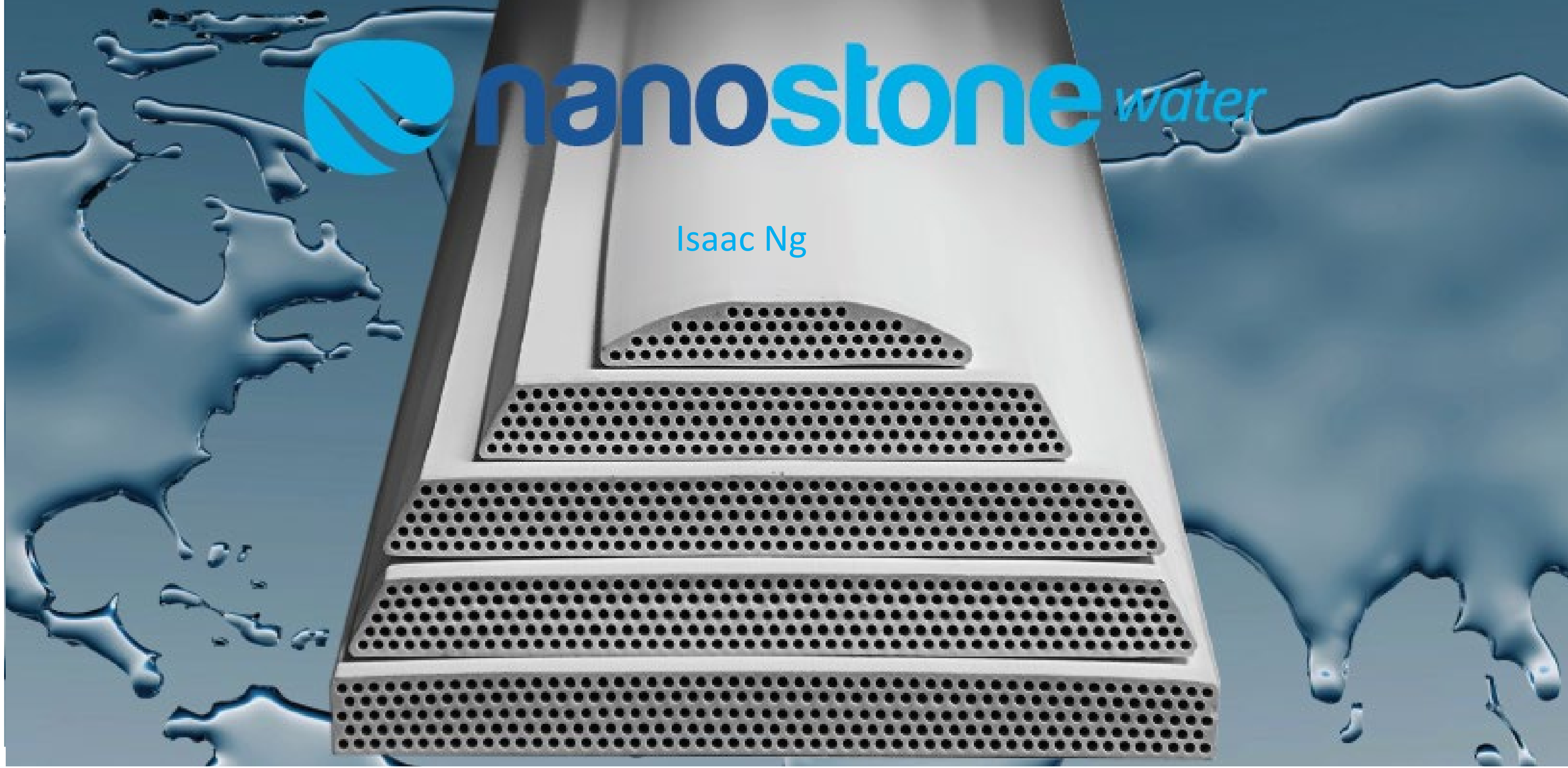


Isaac Ng

Ceramic Ultrafiltration as Pre-treatment for SWRO

SIWW – April 2022

Pre-treatment in desalination

- Reverse Osmosis (RO) is the state-of-the-art technology for seawater desalination
- When provided water free of suspended solids and low in dissolved organics, RO membranes can last for 1-2 years between cleans and a lifetime up to 10 years*
- Conventional RO pretreatment has struggled when faced with challenging intakes resulting in:
  - Capacity loss
  - High cost of cleaning
  - Frequent RO element replacement
- UF membrane pretreatment was expected to address these issues

* Voutchkov "Seawater Pretreatment Challenges and Considerations" www.waterworld.com, March 1st, 2009

Pre-treatment issues

- Seawater challenges
  - Algal blooms / red tide
  - High variability – tidal effect
  - Dissolved organic content (DOC) incl AOC
  - Transparent Exopolymer Particles (TEP)

- Polymeric Membranes
  - Implemented in many plants beginning ~15 years ago to address concerns with conventional treatment (absolute barrier SS)
  - Suitable for surface water but desalination plants have struggled
    - Permit pass-through of DOC & TEP leading to excessive NOM and biofouling of RO
    - Unable to maintain capacity even at extremely low design flux
    - Susceptible to fiber breaking, therefore breakthrough

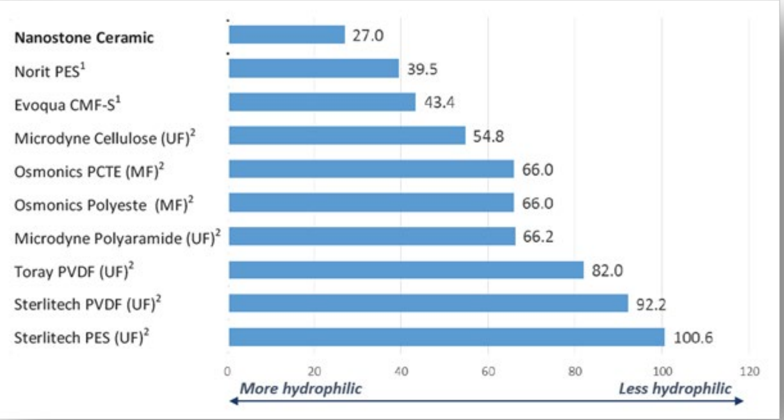
nanostone water

Pre-treatment today

- Dissolved Air Flotation (DAF) now being added ahead of polymeric membranes
  - Adds significant capital cost
  - Requires large footprint
  - High operating cost associated with chemical dosing and sludge removal
  - Is a specified requirement by some major utilities
- “State-of-the-art today is DAF and multi-media filtration”
  - Leading seawater utility manager at Global Water Summit in April 2019
  - Polymeric membranes have failed
- DAF + MMF have their own problems
  - Expensive
  - Footprint
  - Significant risk of solids carry-over
  - Risk of biomass release

Physical advantages ceramic membranes

- Long life expectancy (>20y)
- Integrity
- Rigidity
- Chemical & mechanical tolerance
- Narrow pore size distribution (high permeability)
- Hydrophilic
- Surface charge leading to electrostatic exclusion



Operational advantages ceramic membranes

- Since ceramic membranes have wide feed channels (i.e. 2.4mm), inline coagulation (ILC) is technically feasible to an extent of conventional coagulation (1-25 ppm of metal ion)
- ILC improves filterability and forms a permeable pre-coat leads to significant improvement in membrane performance:
  - Flux >2X higher
  - Filtration cycles or fouling load (L/m2) >3x higher
  - CEB fouling load (L/m2) >2x higher
  - Permeate quality improved (still some DOC removal even at higher pH)
- Costs of coagulant and pH control only fraction of total cost, reduction in CAPEX by membrane area
- ILC can be ‘enhanced’ to further decrease DOC/AOC concentration (30-90% reduction in DOC)
- Coagulation is a very good proven technology to overcome TEP issues related to algal bloom or post algal bloom conditions

Ceramic membranes for pre-treatment SWRO

- Ceramic membranes for large scale applications like pre-treatment for SWRO is still reasonable young technology (2% share of membrane filtration market)
- In ceramic supplier market biggest share 50% for Metawater/PWNT followed by Nanostone 20%
- Nanostone total installed capacity since release June 2017 is 307 MLD
    - municipal: 85 MLD (all retrofits of existing polymeric plants on surface water)
    - industrial: 222 MLD (majority greenfield about 30% retrofits)
    - biggest industrial plant 48 MLD (Wushen Innermongolia China), coal mining
    - biggest municipal plant 54 MLD (Canyon Regional Water Authority, Texas), potable water
- No large-scale SWRO (>1000m3/h) pre-treatment plants yet
- So far data of 2 pilots on seawater and 4 pilots starting this year indicate promising results on ‘state of the art’ issues

Overview or Pilot at Tuas (Singapore PUB)

Tuas derives its intake 1.4 km off-shore

Objectives

- Stable UF-performance at economical feasible flux
- Highest possible NOM/DOC removal for downstream RO
- Absolute filtration for SS (low Turbidity, SDI)

Pre-treatment

- Continuous 5 days 2 ppm NaOCl dose, +6 ppm shock dose for 2 days (8ppm)
- Sieve 20 mm
- Rough screen 2mm (other MF/UF pilots on site have a 400µm or finer screen)
- In-line coagulation with $FeCl_3$, pH-control and 1-3 minute contact time

Logistics

- Trial of 6 months
  - 3 months optimization
  - 3 months longer-term monitoring

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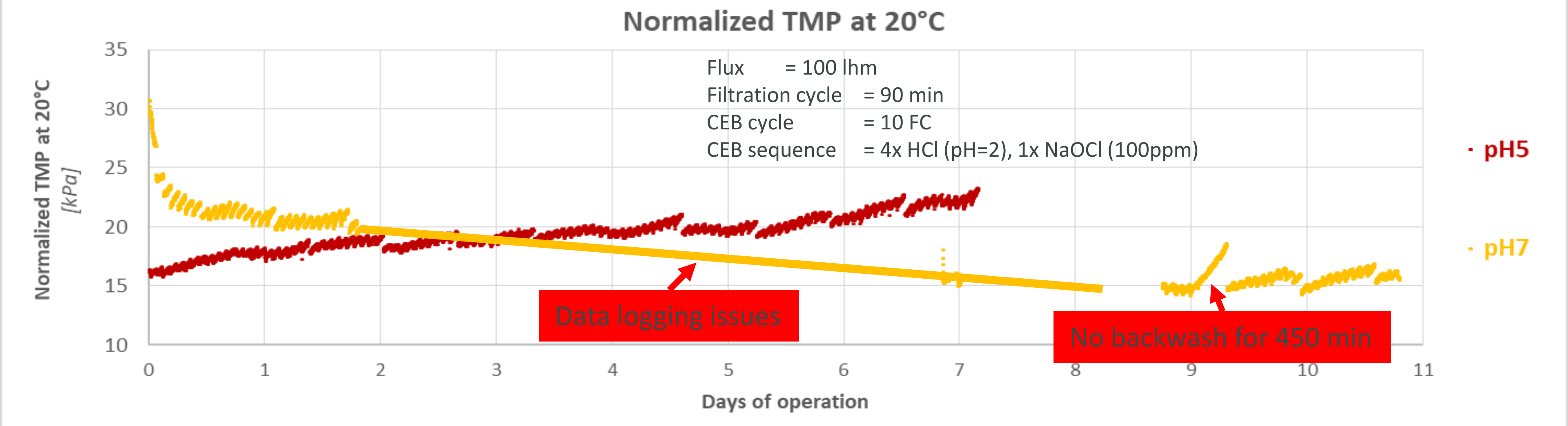
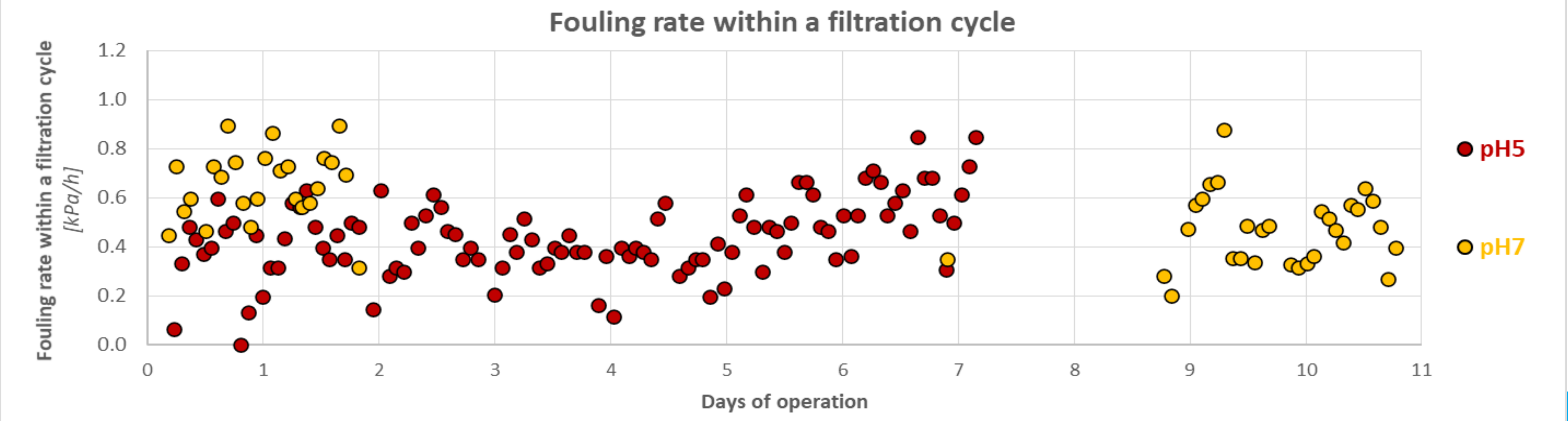
Technical background/research at TUAS (PUB) – Optimizing ILC

- Based on theory expectations for pH 5 are:
  - Closer to “Enhanced” coagulation
  - Higher removal percentage DOC (humic fraction)
  - Some irreversible fouling caused by charged matter
  - Charged metal organic complexes formed
- Based on theory expectations for pH 7 are:
  - Closer to “Sweep” flocculation
  - Lower removal rate DOC (mainly HMW fraction)
  - Less irreversible fouling caused by formation of uncharged $Fe(OH)_3$



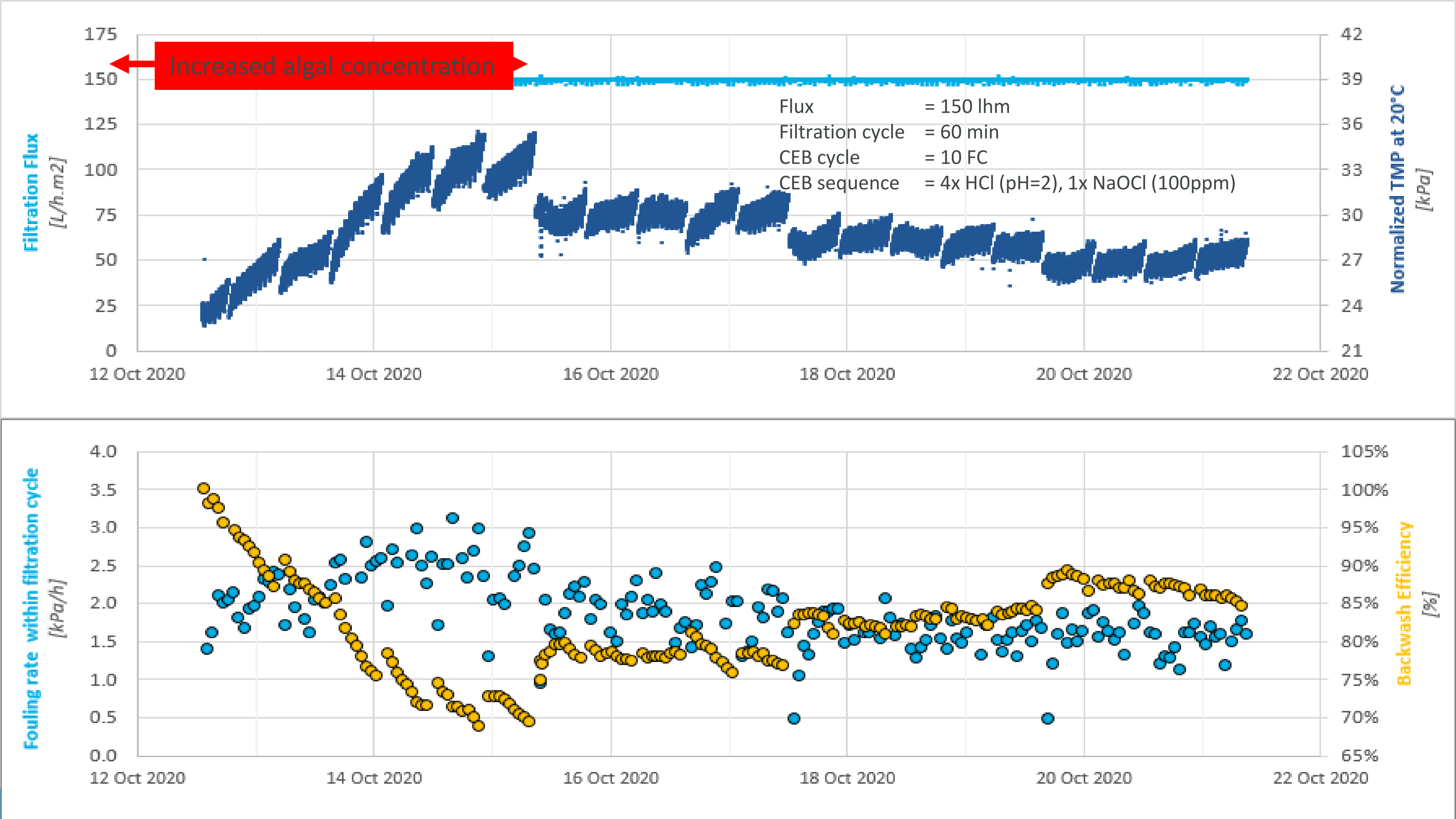
Normalized TMP at 20°C
Normalized TMP at 20°C [kPa]
Flux = 100 lhm
Filtration cycle = 90 min
CEB cycle = 10 FC
CEB sequence = 4x HCl (pH=2), 1x NaOCl (100ppm)
pH5
pH7
Data logging issues
No backwash for 450 min
Days of operation



Fouling rate within a filtration cycle
Fouling rate within a filtration cycle [kPa/h]
pH5
pH7
Days of operation

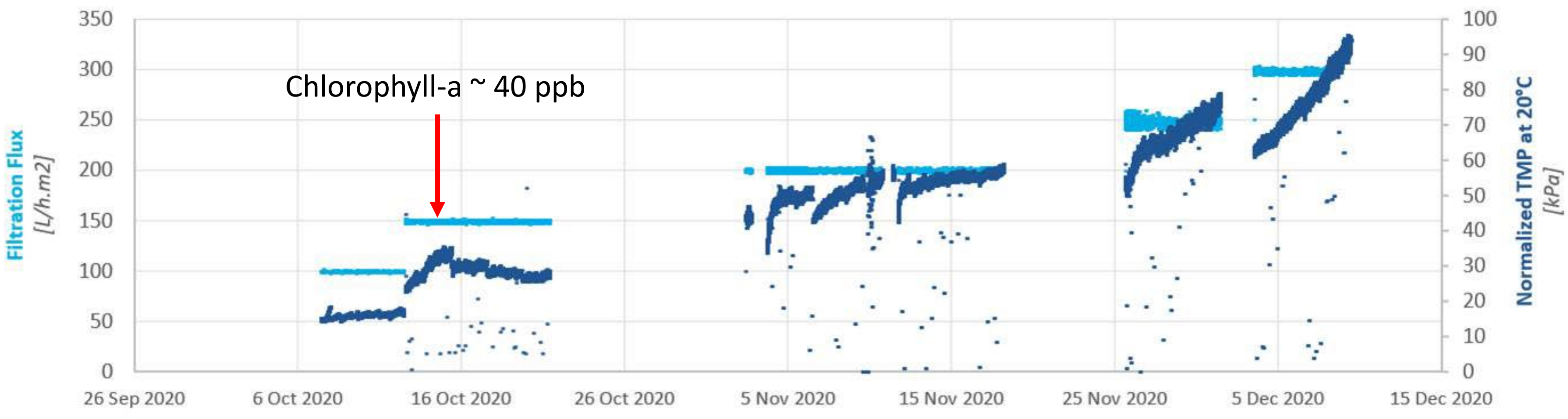
Technical background/research at TUAS (PUB) – Optimizing ILC

- Better overall membrane performance at ‘ sweep’ flocculation at pH=7
- DOC removal higher at ‘enhanced’ coagulation 79% vs 30% but still sufficient enough at pH=7 and 5 ppm Fe^{3+}
- Critical flux determination continued at pH=7 and 5 ppm Fe^{3+}



Increased algal concentration
Flux = 150 lhm
Filtration cycle = 60 min
CEB cycle = 10 FC
CEB sequence = 4x HCl (pH=2), 1x NaOCl (100ppm)
Filtration Flux [L/h.m2]
Normalized TMP at 20°C [kPa]
175
150
125
100
75
50
25
0
42
39
36
33
30
27
24
21
12 Oct 2020
14 Oct 2020
16 Oct 2020
18 Oct 2020
20 Oct 2020
22 Oct 2020
Fouling rate within filtration cycle [kPa/h]
Backwash Efficiency [%]
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
105%
100%
95%
90%
85%
80%
75%
70%
65%

Critical Flux Determination



CIP Frequency:

Fouling rate for 100 lmh run = 0.2761 kPa/day (~360 days CIP frequency)

Fouling rate for 150 lmh run = 0.2951 kPa/day (~340 days CIP frequency)

Fouling rate for 200 lmh run = 2.4313 kPa/day (~45 days CIP frequency)

Fouling rate for 250 lmh run = 3.2266 kPa/day (~31 days CIP frequency)

Fouling rate for 300 lmh run = 4.6611 kPa/day (~22 days CIP frequency)

-Fouling at higher flux mainly caused by BW efficiency loss
-300lmh approached hydraulic limitation of system
-250 lmh chosen to further optimize (stabilization)

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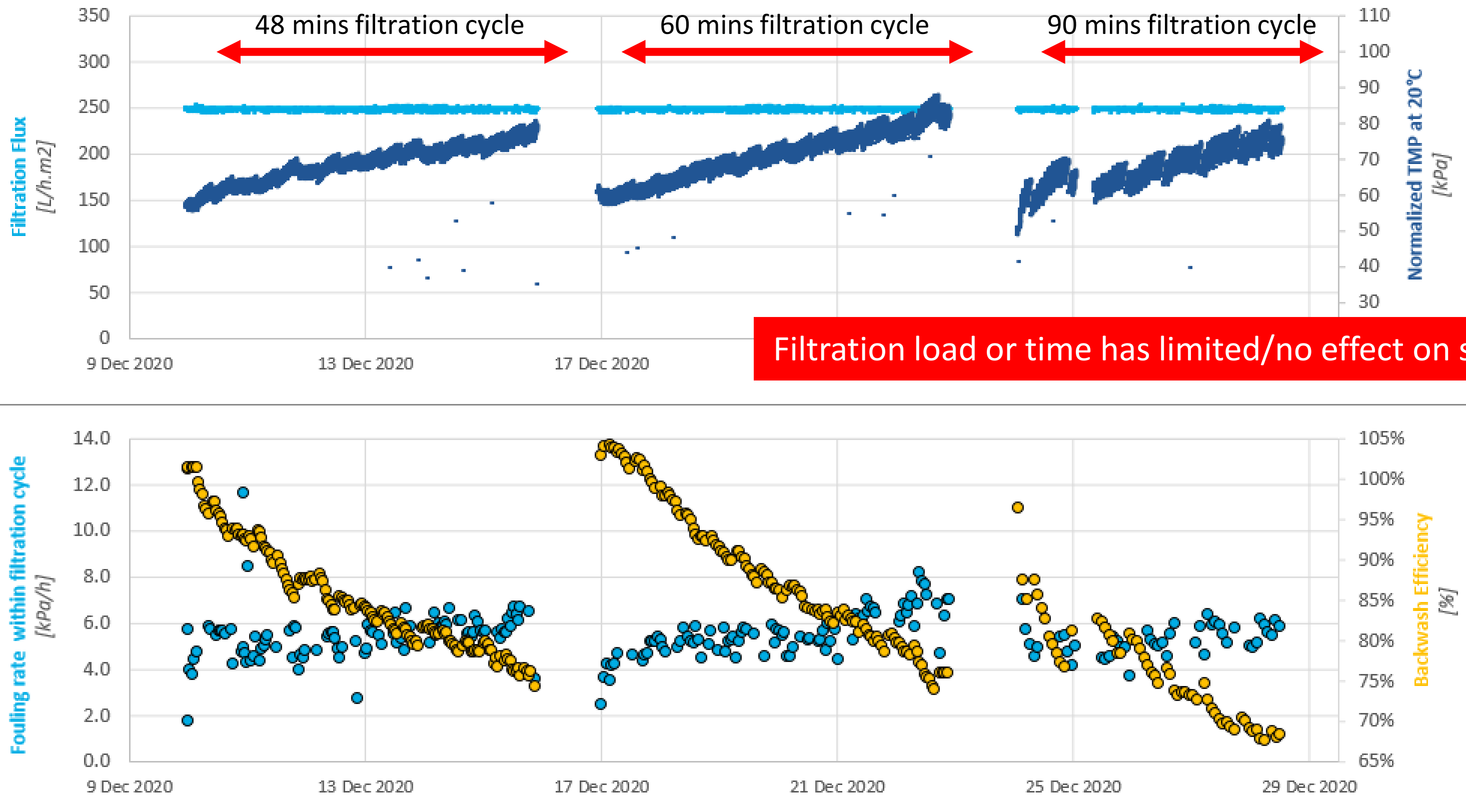
Note: based on initial TMP = 50 kPa and TMP before CIP = 150 kPa

Backwash Frequency Optimization



Filtration load or time has limited/no effect on stability

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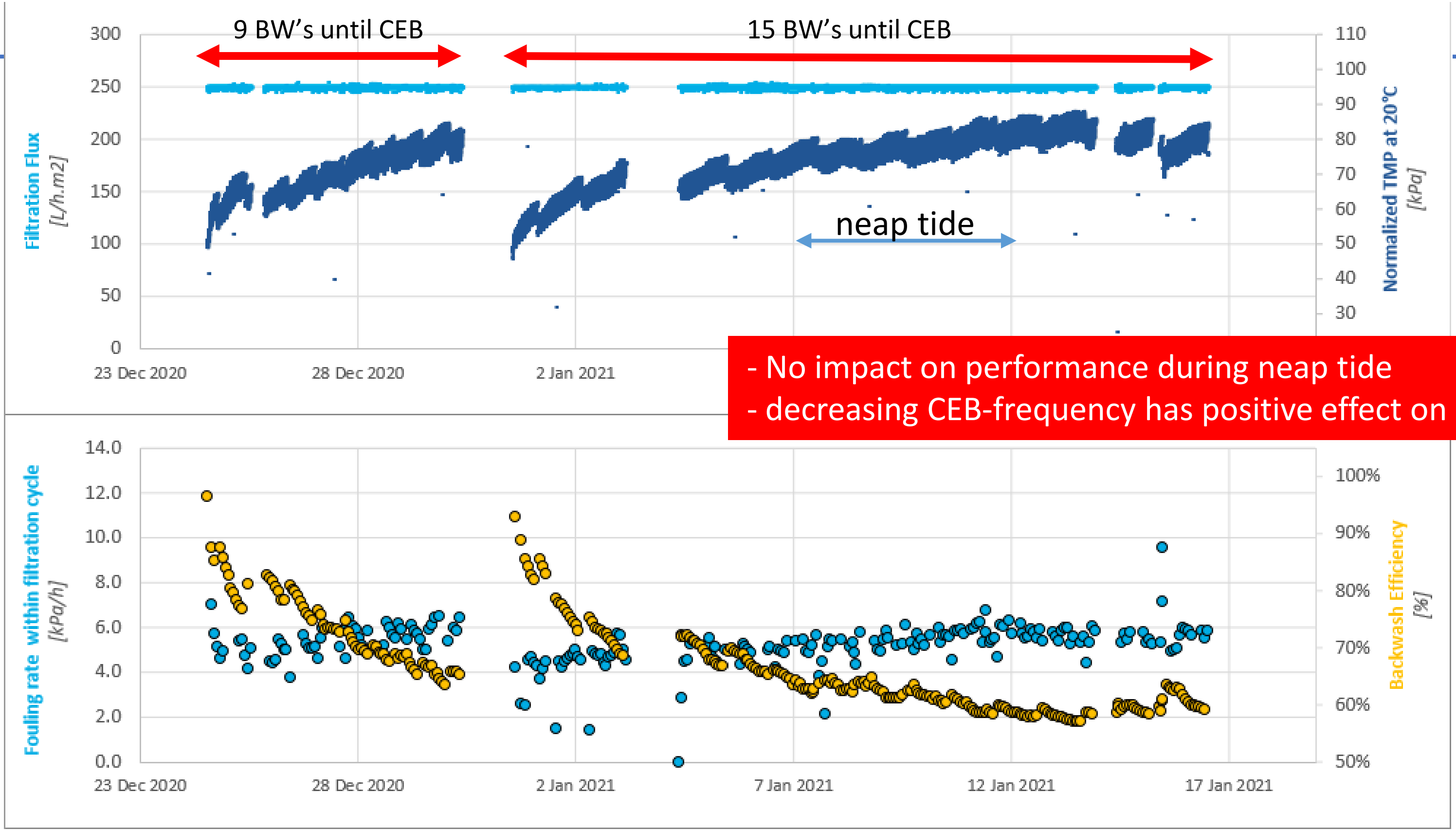
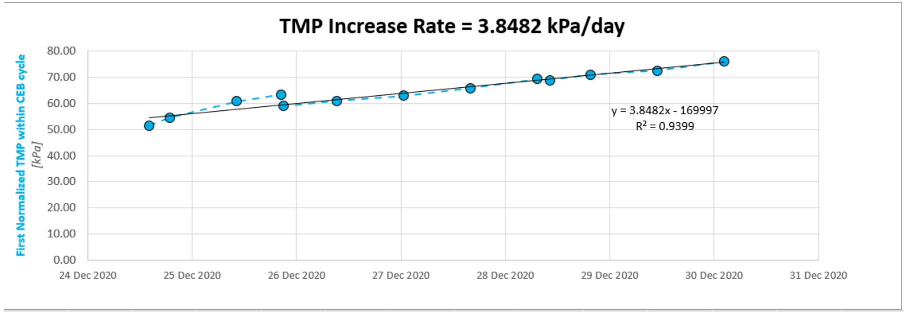
CEB Frequency Optimization



- No impact on performance during neap tide
- decreasing CEB-frequency has positive effect on stability

Estimated CIP Frequency

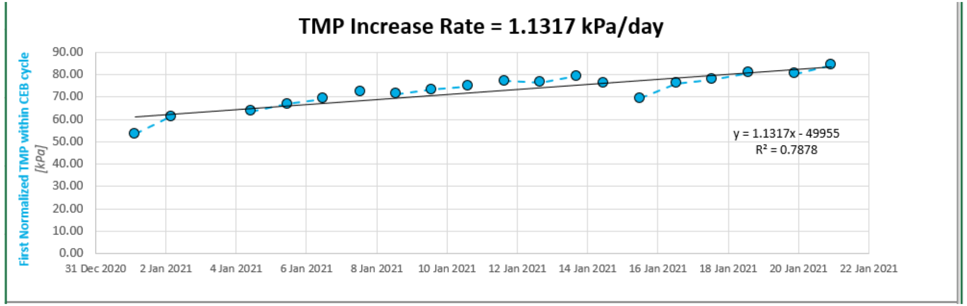
- Flux – 250 lmh with 90 mins filtration cycle
- CEB frequency – after every 9 BW's



CIP frequency = 26 days

Based on initial TMP = 50 kPa and TMP before CIP = 150 kPa

- Flux – 250 lmh with 90 mins filtration cycle
- CEB frequency – after every 15 BW's



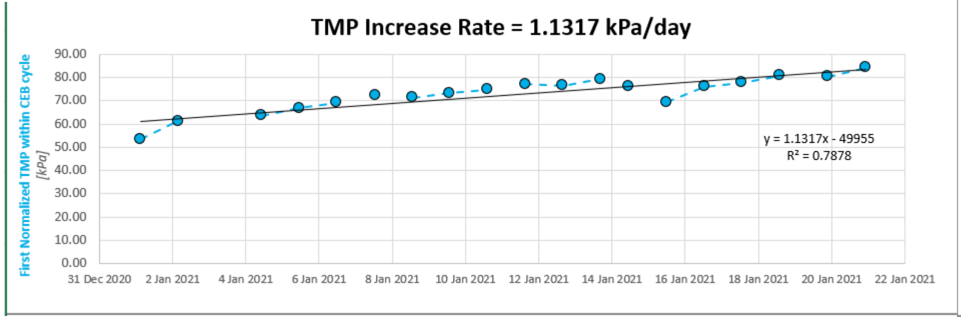
CIP frequency = 89 days

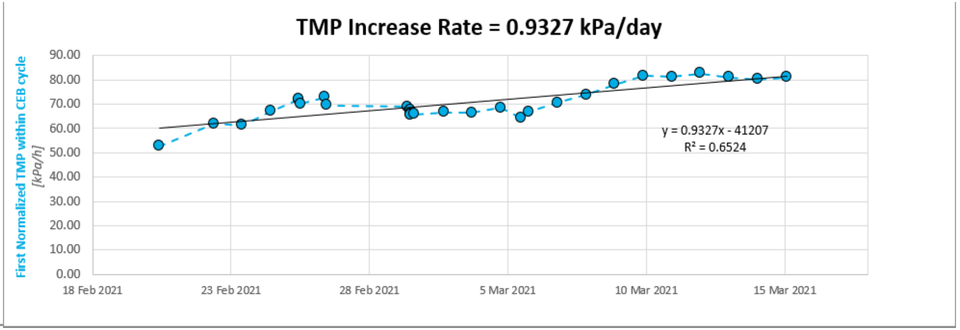
Based on initial TMP = 50 kPa and TMP before CIP = 150 kPa

Long term trial (intake stop 22 Jan - 18 Feb)

- Flux – 250 lmh with 90 mins filtration cycle
- CEB frequency – every 24 hours
- Operation period – 31st Dec 20 – 21st Jan 21 (22 days)
- Fouling rate – 1.1317 kPa/day
- CIP Frequency – 89 days

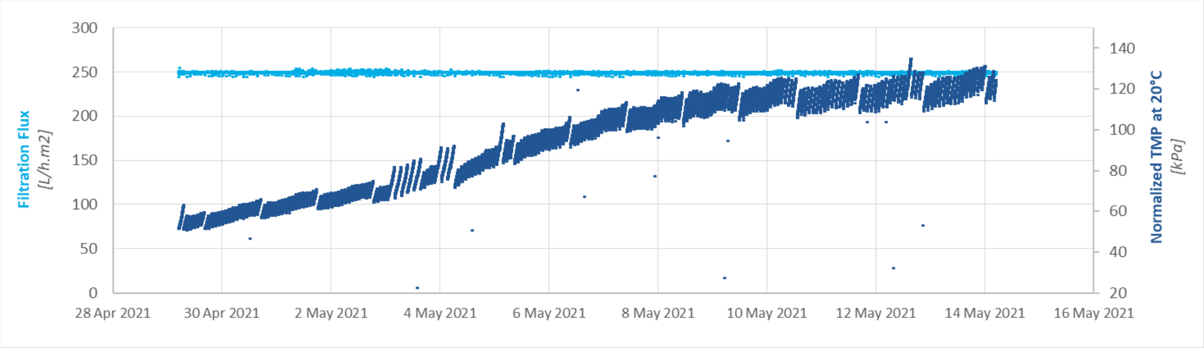
- Flux – 250 lmh with 90 mins filtration cycle
- CEB frequency – every 24 hours
- Operation period – 19th Feb 20 – 15th Mar 21 (26 days)
- Fouling rate – 0.9327 kPa/day
- CIP Frequency – 107 days

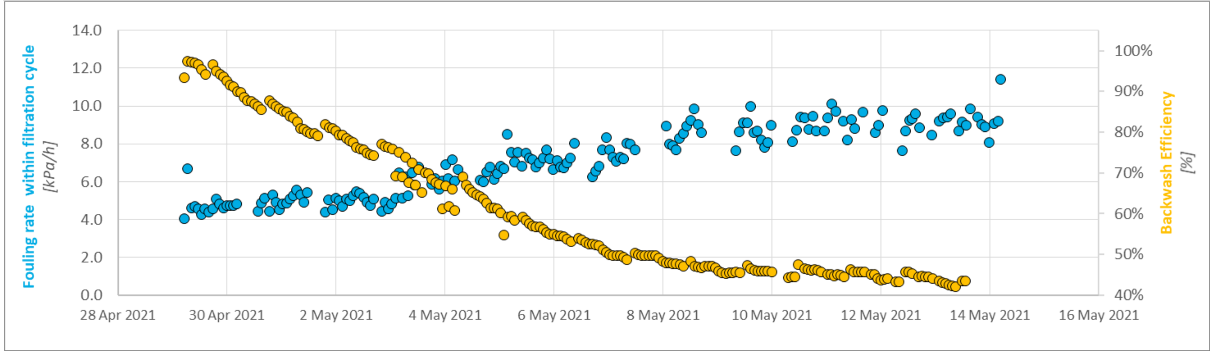




CIP frequency is calculated based on initial TMP = 50 kPa and TMP before CIP = 150 kPa

Marine oil test





For 16 days marine fuel oil was dosed continuously into the feed stream leading to an overall concentration of 1,5 -2,5 mg/L

Oil in the filtrate <0,1 mg/L (below detection limit)

Fouling rate increased initially but tends to stabilize

CIP frequency decreased from 110 to 20 days

After CIP permeability recovered to similar values (>500 lhm.bar)

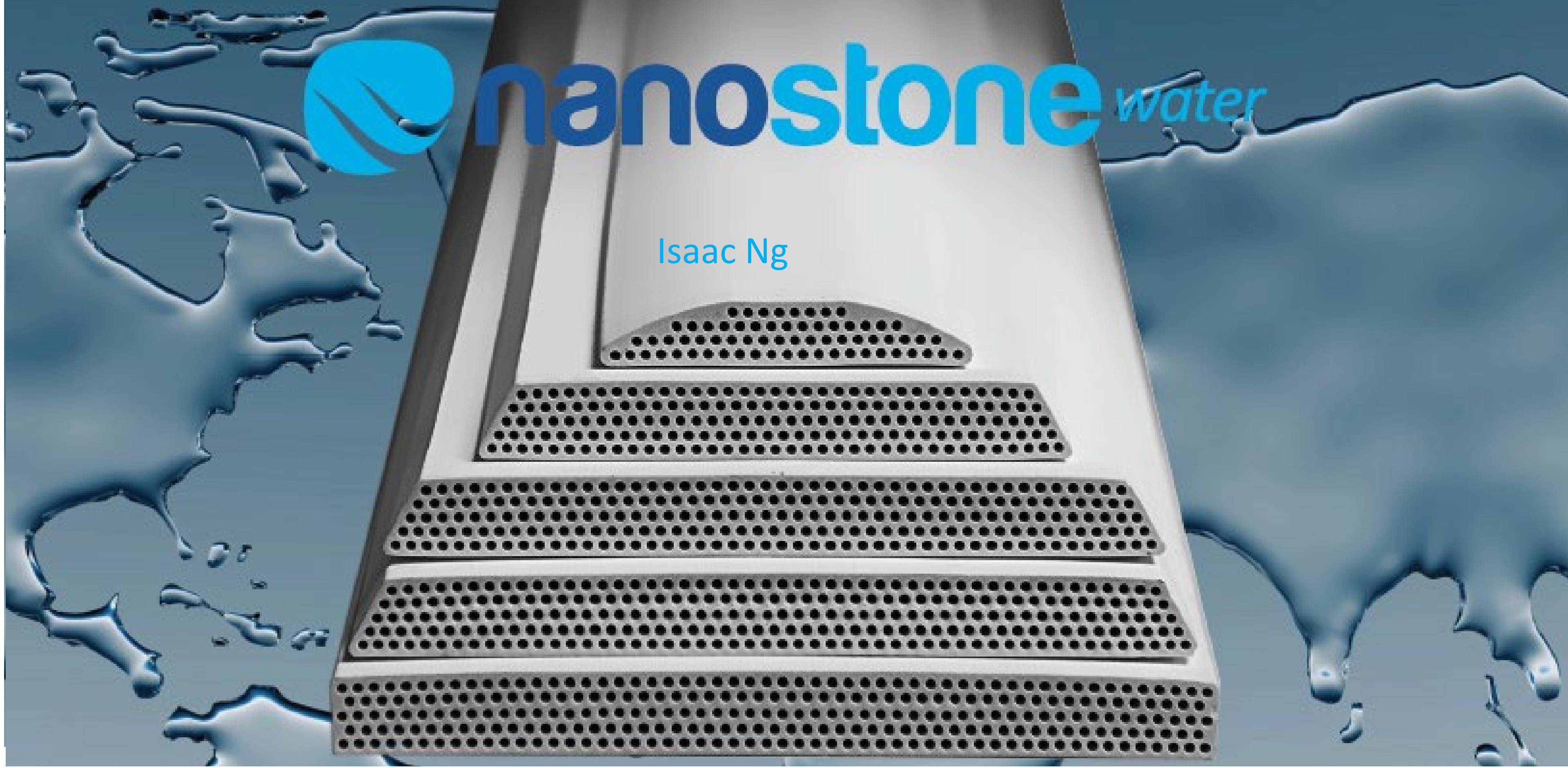
Water Quality permeate

- Total Organic Carbon (TOC) / Dissolved Organic Carbon (DOC): The TOC and DOC of the raw water was in the range of 0.8-2.8 mg/l, while the TOC and DOC of the membrane filtrate was in the range of 0.6-1.2 mg/l. The removal rate was around 30% in average.
- UV Transmittance (UVT): The UVT of water improved from approximately 95% to 97-98% after membrane filtration.
- Turbidity: The turbidity of the raw water was in the range of 1.8-40 NTU, while the membrane filtered water had turbidity below 0.05 NTU.
- Iron: The ceramic membrane effectively lowered the total and dissolved iron concentration to below the level of 0.0045 mg/l.
- SDI_{15}: The filtrate SDI_{15} readings were very good, with all readings being not more than 3, and in average of 2. The SDI_{15} during high algae season were higher than average, which was around 3.
- Oil & Grease: The oil and grease concentration in the filtrate was < 0.1 mg/l during the marine fuel oil spike test.

Summary of Testing and Conclusions at TUAS

- Membrane operation is stable during algae blooms and tide events with *negligible impact on performance*
- Established operating parameters demonstrate economically attractive set points
  - Flux 250 lhm at 90 min filtration cycles
  - CEB after 15 FC cycles (approx. 1/day)
- Demonstrated, sustainable and stable flux means:
  - Reduced footprint
  - Reduced CAPEX
- Demonstrated operational set points mean:
  - Increased water production efficiency - >98% water recovery
  - Increased up time and lower OPEX
- A robust, reliable and cost-effective solution for desalination pre-treatment at TUAS

Special thanks to Singapore PUB and the authors of the paper – Jonathan Clement and Gilbert Galjaard.



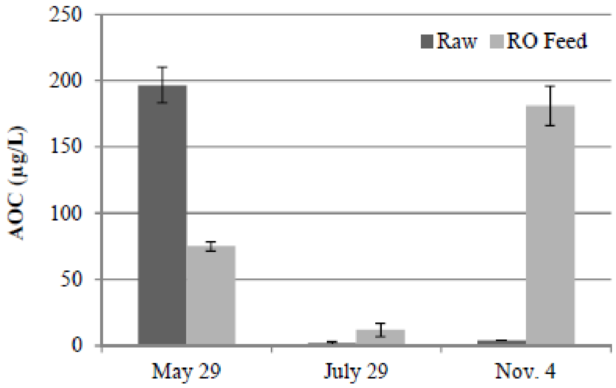
Isaac Ng

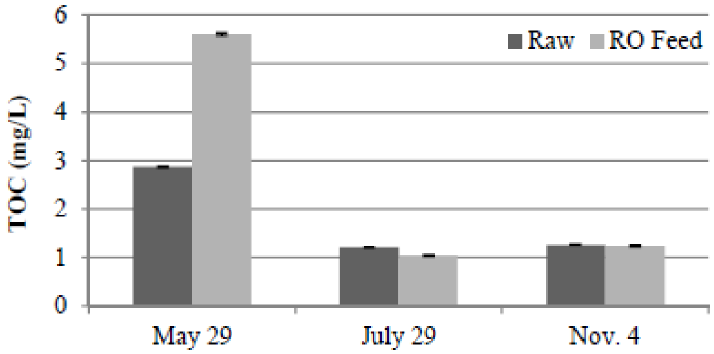
Ceramic Ultrafiltration as pre-treatment for SWRO

SIWW – April 2022

Inconsistent quality biological active filters

- While ‘enhanced’ coagulation removes a steady amount of DOC/AOC, DMF with layer of pumice leads to biological active filters also releasing DOC/AOC in times when nutrients going in are less and biomass dies leading to increase in TOC/AOC levels towards RO (i.e. thesis L.A. Weinrich 2015, Al Zawrah plant)





Al Zawrah organic carbon raw and RO feed 2012 , pre-treatment RO DMF with 800mm pumice & cartridge filters