Pre-treatment with Ceramic Membranes for Desalination

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PWNT
Acknowledgements

- Wabag
- PUB staff
- METAWARET staff, Japan
Overview

- Desalination pre-treatment
- Ceramic membranes
- Test Data
Desalination pre-treatment

- Neglected
- Most or almost all research is on reducing energy
- Considered by most nothing special
- Often place burden on RO
- Large plants sizes – considerable investment
Desalination pre-treatment

- Harshly arbitrary
- Disregard for specific requirements
- Simply applying standard surface water technologies for desalination pre-treatment
- No or little recognition of the nature of sea water
- Serious problems with polymeric membranes – little open scientifically credible discussion
Singapore’s shift

- Tenders for desalination pre-treatment will not allow stand alone use of polymeric membranes – must be proceeded by DAF
- Algae and other matter are causing serious problems will diminished permeability
Start with right question

- What do we want specifically for desalination pretreatment?
- Robust capable of withstanding chemical composition of sea water
- High recovery
- Compact
- Integrity – capable of enhancing and protecting downstream treatment
Aging of Membranes over 5 years
Ceramic membrane advantages

- long life expectancy 30 years
- capability to use strong cleaning chemicals and oxidants
- no risk of fiber breakage
- very narrow pore size distribution
- can be operated with very high backwash rates and BW pressure
- minimal pre-treatment and can handle high turbidity and high solids waters
recovery at different runs

Recovery (%)

- Runs without ozone
- Runs with ozone

Test run
Long service life (Complete recovery by CIP)

Permeability is completely recovered by CIP for 15 years
Composition of Ceramics

- **Sintering Process**
  - Various forms of $\text{Al}_2\text{O}_3$
- **Can contain ZrO2 and TiO2 opportunity for others**

What does this mean – different surface chemistry reactions than polymeric-adsorption phenomena onto metal oxides.
Objectives

- Observe the performance of ceramic membranes as a pretreatment for seawater desalination
- Determine filtered water quality (turbidity, SDI, DOC, etc.)
- Determine operational and design parameters
Background

- **Pilot Operation:**
  - June 2015 to June 2016
  - pilot operated at PUB Tuaspring facility
  - operated by PWNT staff and Metawater
  - initial test runs with PACI
  - after 1 July 2015 – all test runs with ferric chloride coagulant
  - ferric chloride coagulant chosen because of high soluble aluminium in filtrate when using PACI (unable to correct pH)
Pilot Plant

- METAWATER single element pilot
  - coagulation/mixer/flocculation
  - 25m² ceramic microfilter (0.1 micron)

- Protocol
  - critical flux tests with coagulant
  - long-term testing

- Water source
  - pre-screened and pre-chlorinated seawater
Membrane operation

- Enhanced backwashes (EBW)
  - 100 mg/l chlorine
  - pH 2 with sulphuric acid
  - Conducted after 9 normal backwashes
  - 4 chlorinated EBW to 1 acid EBW

- CIP
  - Facility to perform CIP not possible, so an extended EBW was performed
## Water Quality

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Raw Water</th>
<th>Filtrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total aluminium*</td>
<td>mg/l</td>
<td>0.06 – 0.29 (0.17 av)</td>
<td>0.05 – 0.83 (0.58 av)</td>
</tr>
<tr>
<td>Dissolved aluminium*</td>
<td>mg/l</td>
<td>0.02 – 0.15 (0.58 av)</td>
<td>0.44 – 0.75 (0.58 av)</td>
</tr>
<tr>
<td>Total iron</td>
<td>mg/l</td>
<td>0 – 0.86 (0.15 av)</td>
<td>0 – 0.34 (0.01 av)</td>
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<tr>
<td>Dissolved iron</td>
<td>mg/l</td>
<td>0 – 0.08</td>
<td>0 – 0.04</td>
</tr>
<tr>
<td>Free chlorine</td>
<td>mg/l</td>
<td>0 – 0.79 (0.14 av)</td>
<td>ND</td>
</tr>
<tr>
<td>pH</td>
<td>--</td>
<td>7.2 – 8.1 (7.8 av)</td>
<td>6.1 – 8.0 (7.5 av)</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0.45 – 21 (3.9 av)</td>
<td>0.05 – 0.5 (0.06 av)</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/l</td>
<td>0.5 – 5.7 (1.8 av)</td>
<td>0.05 – 5.4 (1.9 av)</td>
</tr>
<tr>
<td>DOC</td>
<td>mg/l</td>
<td>0.5 – 5.0 (1.3 av)</td>
<td>0.05 – 5.24 (1.2 av)</td>
</tr>
<tr>
<td>Chlorophyll-a</td>
<td>ug/l</td>
<td>0.85 – 5.72 (1.8 av)</td>
<td>0.29 – 1.88 (0.86 av)</td>
</tr>
<tr>
<td>SDI</td>
<td>--</td>
<td>NA</td>
<td>0.83 – 3.4 (2.0 av)</td>
</tr>
</tbody>
</table>

* When using PACI
LC-OCD analysis (example)

- Biopolymers
- Humics
- Building blocks
- LMW acids and HS
- Neutrals

Signal (\(-\))

Retention time (minute)
Organics characterization

Liquid chromatography – organic carbon detection results

<table>
<thead>
<tr>
<th>Organic Parameter</th>
<th>Concentration (mg/L)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOC</td>
<td>1.8</td>
<td>100</td>
</tr>
<tr>
<td>Hydrophobic</td>
<td>0.25</td>
<td>13.7</td>
</tr>
<tr>
<td>Hydrophilic</td>
<td>1.58</td>
<td>86.3</td>
</tr>
<tr>
<td>Biopolymers</td>
<td>0.1</td>
<td>5.7</td>
</tr>
<tr>
<td>Humics</td>
<td>0.4</td>
<td>23.6</td>
</tr>
<tr>
<td>Building blocks</td>
<td>0.2</td>
<td>10.8</td>
</tr>
<tr>
<td>LMW neutrals</td>
<td>0.84</td>
<td>46.1</td>
</tr>
</tbody>
</table>
Ceramic membrane element

Nominal pore size: 0.1μm

Dimension: φ180mm x 1,500mmL

Membrane surface area: 25m²

Size of channel: 2.5mm

Number of channel: 2,000

Material: Ceramics

Support layer

Separation layer

2.5 mm
Schematic flow into the ceramic membrane

Mnemonic filtration channels

Filtrate collection channels

Membrane filtration channels (φ2.5mm)

Filtrate

Element

Raw water

< Inside flow >

Raw water channels

Filtrate collection channels

Raw seawater
TMP profile

Run 3 to 9 June 2015
Flux: 150 l/mh
BW interval: 20 minutes
No. BWs until an EBW: 9
coagulant dosage: 1.9 mg/l Al (PACl)
Run 12 to 25 August 2015
Flux: 175 lmh
BW interval: 17 minutes
No. BWs until an EBW: 9
coaugulant dosage: 2.6 mg/L Fe
TMP profile

Run 2 to 8 Sept 2015
Flux: 175 then 200 l/mh
BW interval: 15 minutes
No. BWs until an EBW: 9
coagulant dosage: 2.6 mg/L Fe
Run 23 to 29 Sept 2015
Flux: 200 then 175 lmh
BW interval: 20 minutes
No. BWs until an EBW: 9
Coagulant dosage: 2.6 mh/l Fe (FeCl3)
Auto-recovery with lower flux.
TMP profile

Run: 14 to 20 October 2015
Flux: 175 lmh
BW interval: 20 minutes
No. BWs until an EBW 9
coagulant dosage: 2.6 mg/L Fe
Run 2 to 8 December 2015
Flux: 150 lmh
BW interval: 20 minutes
No. BWs until an EBW: 9
coagulant dosage: 2.8 mg/L Fe

The cause of elevated TMP is unknown.
Erroneous pilot set-point stopped operation at TMP > 100 kPa
Turbidity

TURBIDITY

Feed

Filtrate

Turbidity, NTU

Turbidity, NTU

20/05/15 09/07/15 28/08/15 17/10/15 06/12/15 25/01/16 15/03/16 04/05/16 23/06/16 12/08/16
Iron

IRON

Feed - Total  Filtrate - Soluble

COAGULANT
PACl
COAGULANT
FeCl3

Iron, mg/l

0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

16/05/15 05/07/15 24/08/15 13/10/15 02/12/15 21/01/16 11/03/16 30/04/16 19/06/16 08/08/16
UVT

UVT, %

- Raw Water
- Filtrate

Graph showing UVT values from 16/05/15 to 08/08/16.
Chlorophyll-a

**CHLOROPHYLL-A**

- **Feed**
- **Filtrate**
- **Series3**
- **Series4**

Chlorophyll-a, ug/l

<table>
<thead>
<tr>
<th>Date</th>
<th>Chlorophyll-a, ug/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>16/03/16</td>
<td>5.5</td>
</tr>
<tr>
<td>26/03/16</td>
<td>0.5</td>
</tr>
<tr>
<td>05/04/16</td>
<td>1.0</td>
</tr>
<tr>
<td>15/04/16</td>
<td>2.5</td>
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<tr>
<td>25/04/16</td>
<td>3.0</td>
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<td>5.0</td>
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<tr>
<td>25/05/16</td>
<td>6.0</td>
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<tr>
<td>04/06/16</td>
<td>7.0</td>
</tr>
<tr>
<td>14/06/16</td>
<td>8.0</td>
</tr>
</tbody>
</table>
Pilot findings

• EBW with NaOCl at 100 mg/l
• EBW at pH < 2 with H₂SO₄
• High recovery >94%
• Low SDI
• Ferric chloride versus aluminium bases
Conclusions

- Highly stable flux at 170 l/mh
- Limited chemical cleaning
- Much more research work to be done on optimizing chemistry
  - Hydrogen peroxide, high pH cleaning regimes
- Compact compared to alternatives
- Investigating impact of pH on fouling