ACHIEVING THE ZLD TARGET USING INTEGRATED MEMBRANE SYSTEM FOR SEAWATER DESALINATION

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CONTENTS

1. OVERVIEW OF THE DESALINATION TECHNOLOGIES
2. THE ROLE OF MEMBRANE DISTILLATION IN THE INTEGRATED MEMBRANE SYSTEM
3. ECONOMICAL INVESTIGATION & SENSITIVITY STUDY
4. CONCLUSIONS AND REMARKS
<table>
<thead>
<tr>
<th>Process</th>
<th>Energy consumption kWh/m³</th>
<th>Feed TDS (mg/L)</th>
<th>Product TDS (mg/L)</th>
<th>Required space</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSF (Thermal Desalination)</td>
<td>10.3 – 13</td>
<td>20,000 – 500,000</td>
<td>&lt;10</td>
<td>Very large</td>
</tr>
<tr>
<td>MED (Thermal Desalination)</td>
<td>6.5 – 8.5</td>
<td>20,000 – 500,000</td>
<td>&lt;10</td>
<td>Large</td>
</tr>
<tr>
<td>EDR (Membrane Desalination)</td>
<td>0.6 – 4.2</td>
<td>3,000 – 12,000</td>
<td>&lt;10</td>
<td>Small</td>
</tr>
<tr>
<td>RO (Membrane Desalination)</td>
<td>3.5 – 3.8</td>
<td>5,000 – 50,000</td>
<td>&lt;500</td>
<td>Small</td>
</tr>
</tbody>
</table>

• IDA Worldwide Desalting Plants Inventory Report No 18; published by Wangnick Consulting 2004
EMBRANE DISTILLATION (MD)

- Emerging separation technology
- Transport of vapor through hydrophobic membrane
- Based on vapor-liquid equilibrium
- Driving force is temperature difference
LIMITATIONS OF THE DESALINATION TECHNOLOGIES

- Low efficiency
- Environmental impact
- Water quality
- Product water cost

Can be improved by combining several desalination processes in one integrated system
To perform economical investigations and sensitivity study for evaluating several combinations of the integrated membrane system
INTEGRATED MEMBRANE SYSTEM

Total system recovery 95%

95% MF

Filtered Seawater

70%

NF Retentate

Heat source

Salt Crystals

MD

Concentrate

Heat source

Potable water

60% RO

Filtered Seawater

Potable water

NF Retentate

Brine

Raw Seawater 70%

NF

Potable water

NF Product

MF Retentate

INTEGRATED MEMBRANE SYSTEM
ECONOMICAL INVESTIGATION
### Reference values for cost analysis

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF Membrane cost</td>
<td>90 $/m²</td>
</tr>
<tr>
<td>NF and RO Membrane cost</td>
<td>30 $/m²</td>
</tr>
<tr>
<td>Membrane life</td>
<td>6.7 years</td>
</tr>
<tr>
<td>Electricity cost</td>
<td>0.03 $/kWh</td>
</tr>
<tr>
<td>Steam cost</td>
<td>7 $/ton</td>
</tr>
<tr>
<td>Plant capacity</td>
<td>24,000 m³/day</td>
</tr>
</tbody>
</table>
ECONOMICAL INVESTIGATIONS

FLOW & WATER COST

- **Feed**
- **Concentrate**
- **Water cost**

<table>
<thead>
<tr>
<th>Process</th>
<th>Flow (m³/h)</th>
<th>Feed</th>
<th>Concentrate</th>
<th>Water Cost ($/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF-RO</td>
<td>1000</td>
<td>0.51</td>
<td>1506</td>
<td>2105</td>
</tr>
<tr>
<td>MF-NF-RO +MC+MD</td>
<td>1250</td>
<td></td>
<td>68</td>
<td>1124</td>
</tr>
<tr>
<td>MF-NF-RO +MC+MC</td>
<td>1124</td>
<td></td>
<td>14</td>
<td>1068</td>
</tr>
<tr>
<td>MF-NF-RO +MD+MD</td>
<td>1191</td>
<td></td>
<td>131</td>
<td>1191</td>
</tr>
</tbody>
</table>
1. Water Recovery (Yield)
2. Feed Concentration
3. Membrane Cost
4. Electricity Cost
5. Steam Cost
1. WATER RECOVERY (YIELD)

RO Recovery in MF-RO

RO Recovery in MF-NF-RO

MD Recovery in MD alone

ER=Energy Recovery; HR=Heat Recovery systems
2. FEED CONCENTRATION

MF-NF-RO PLANTS

- Without ER
- With ER

0.7
0.6
0.5
0.4
0.3

Feed Concentration (g/L)

Water cost ($/m³)

Seawater:
- 15%

Brackish:
- 16%

MD PLANTS

- Without HR
- With HR

1.4
1.3
1.2
1.1
1.0

Feed Concentration (g/L)

Water cost ($/m³)

NO CHANGES

INTEGRATED SYSTEM

- Without ER+HR
- With ER+HR

1.8
1.6
1.4
1.2
1.0

Feed Concentration (g/L)

Water cost ($/m³)

Seawater:
- 2%

Brackish:
- 3%

ER=Energy Recovery; HR=Heat Recovery systems
3. MEMBRANE COST

Reference: MF=90 $/m^2, NF & RO=30 $/m^2

**MF-NF-RO PLANTS**

- Without ER
- With ER

Reference value:
- MF = 90 $/m^2
- NF and RO = 30 $/m^2

**MD PLANTS**

- Without HR
- With HR

Reference value:
- MD = 90 $/m^2

**INTEGRATED SYSTEM**

- Without ER+HR
- With ER+HR

Reference value:
- MF and MD = 90 $/m^2
- NF and RO = 30 $/m^2

ER=Energy Recovery; HR=Heat Recovery systems
4. ELECTRICITY COST  
Reference: Electricity cost = 0.03 $/kWh

**MF-NF-RO PLANTS**

- **Without ER**
- **With ER**

- **Water cost variations (%)**

- **Electricity cost variations (%)**

- **Reference value electricity cost = 0.03 $/kWh**

**MD PLANTS**

- **Without HR**
- **With HR**

- **Water cost ($/m^3)**

- **Electricity cost variations (%)**

- **NO CHANGES**

**INTEGRATED SYSTEM**

- **Without ER+HR**
- **With ER+HR**

- **Water cost variations (%)**

- **Electricity cost variations (%)**

- **Reference value electricity cost = 0.03 $/kWh**

ER=Energy Recovery; HR=Heat Recovery systems
5. STEAM COST

SENSEITIVITY STUDY

Reference: Steam=7 $/ton

MD PLANTS

INTEGRATED SYSTEM

ER=Energy Recovery; HR=Heat Recovery systems
The pressure-driven membranes were very sensitive to the changes in the feed concentration and the cost of electricity.

MD was very sensitive to changes in the steam costs.

The best tolerance to the variation of these parameters was obtained when using the integrated membrane system.

The integrated membrane system was very attractive for satisfying the ZLD concept.
THANK YOU
### Assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant availability, $f$</td>
<td>90 %</td>
</tr>
<tr>
<td>Plant capacity, $Q_p$</td>
<td>24,000 m$^3$/day</td>
</tr>
<tr>
<td>Plant life, $n$</td>
<td>20 years</td>
</tr>
<tr>
<td>Membrane life</td>
<td>6.7 years</td>
</tr>
<tr>
<td>Interest rate, $i$</td>
<td>5 %</td>
</tr>
</tbody>
</table>

### Fluxes

- UF flux = 90 L/m$^2$h
- NF flux = 28 L/m$^2$h
- RO flux = 15 L/m$^2$h
- MD flux = 8.2 L/m$^2$h
- MC flux = 6.8 L/m$^2$h

### Efficiencies

- Pumps-motor combined efficiency = 0.75
- Pressure exchanger efficiency = 0.95
- Heat exchanger efficiency = 0.8

### Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of MF membranes</td>
<td>90 $/m$^2</td>
</tr>
<tr>
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