Desalination

An option for the future

Desalination Plants
### Top 10 desalination countries (2008)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>MCM/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Saudi Arabia</td>
<td>10.8</td>
</tr>
<tr>
<td>2</td>
<td>UAE</td>
<td>8.4</td>
</tr>
<tr>
<td>3</td>
<td>USA</td>
<td>8.1</td>
</tr>
<tr>
<td>4</td>
<td>Spain</td>
<td>5.2</td>
</tr>
<tr>
<td>5</td>
<td>Kuwait</td>
<td>2.9</td>
</tr>
<tr>
<td>6</td>
<td>Algeria</td>
<td>2.7</td>
</tr>
<tr>
<td>7</td>
<td>China</td>
<td>2.3</td>
</tr>
<tr>
<td>8</td>
<td>Qatar</td>
<td>1.7</td>
</tr>
<tr>
<td>9</td>
<td>Japan</td>
<td>1.5</td>
</tr>
<tr>
<td>10</td>
<td>Australia</td>
<td>1.2</td>
</tr>
<tr>
<td>11</td>
<td>Israel</td>
<td>0.8</td>
</tr>
</tbody>
</table>

1% of fresh water comes from desalination
Available Technologies

- Membrane-based Technologies
  - Reverse Osmosis (RO)
  - Electrodialysis (ED) and ED Reversal (EDR)
  - [Low pressure membrane technologies = UF, MF]

- Distillation Technologies
  - Multi-stage flash distillation (MSF)
  - Multiple effect distillation (MED)
  - Vapor compression distillation (VC)

- Alternative Technologies
  - Freezing
  - Membrane distillation
  - Solar humidification

World desalination capacity by process
Reverse Osmosis (RO)

Source: AWWA

2 MGD Oceanside, CA RO Installation
Membrane-Based Technologies

- Microfiltration (MF): 10-0.1μm - bacteria, suspended solids
- Ultrafiltration (UF): 0.05-0.005μm - colloids, volatile organics, macromolecules, virus (and color&odor)
- Nanofiltration (NF): 5-0.5nm – sugars, dyes, divalent salts; water softening, sulfate removal
- Reverse Osmosis (RO): 0.5-0.05nm – monovalent salts, ionic salts
- Electrodialysis (ED) and electrodialysis reversal (EDR)
Multi-Stage Flash Distillation (MSF)

Source: ABC of Desalination, O.K. Buros, 2000
## Process Characteristics

<table>
<thead>
<tr>
<th></th>
<th>RO</th>
<th>EDR</th>
<th>MSF/MED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preferred Water Source</strong></td>
<td>Any</td>
<td>Brackish</td>
<td>Seawater - Brine</td>
</tr>
<tr>
<td><strong>Susceptibility to scaling</strong></td>
<td>high</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td><strong>Bacterial Contamination</strong></td>
<td>Possible</td>
<td>Post-treatment always needed</td>
<td>Unlikely</td>
</tr>
<tr>
<td><strong>Final Product Salinity</strong></td>
<td>On demand (&lt;500 mg/L TDS)</td>
<td>On demand (&lt;500 mg/L TDS)</td>
<td>Can be &lt;10 mg/l TDS</td>
</tr>
<tr>
<td><strong>Energy Cost</strong></td>
<td>Moderate, increases with salinity</td>
<td>High, increases fast with salinity</td>
<td>High, independent of salinity</td>
</tr>
<tr>
<td><strong>Recovery</strong></td>
<td>Typically 50% for seawater, &gt;80% for brackish water</td>
<td>&gt;80% for brackish water</td>
<td>Poor= 10-25%</td>
</tr>
<tr>
<td><strong>Plant Size</strong></td>
<td>Modular, easy to operate, small footprint</td>
<td>Modular, easy to operate, small footprint</td>
<td>Large complex plants</td>
</tr>
</tbody>
</table>
Pre-treatment

- Pre-treatment is an important step of RO and could be a significant fraction of total cost:
  - Removal of particulates: MF
  - Removal of colloids to limit membrane fouling: chemical coagulation (alum, activated silica) or UF
  - Scaling issues: lime addition, softening (NF or ion exchange) to remove Ca/Mg, acidification to regulate pH
Desalination Economics

- **Main problem**: over-high cost and investment cost
  - Municipal water tariff expected to converge with cost of desalination 2010-2015,
  - Sea water 0.6-1.0 USD/m³,
  - Brackish water 0.3 USD/m³
  - Cf. regular drinking water 0.3 USD/m³
Notes on Cost

- RO pressure requirement for brackish water is much less than that for seawater, desalination of brackish water is less expensive than desalination of sea water.
- EDR is currently cost-effective only for low salinity sources
- Distillation-based technology cost is not function of salinity, they make sense only for higher salinity sources (seawater)
Economics

- Co-location
- Cogeneration
- Improved technology
- Decreasing capital and operational costs
- Energy price variability

Typical costs for a very large seawater thermal desalination plant
Cost Trends

Energy: In 6 years costs have dropped from 12 kWh/m³ to 3.2 kWh/m³

Source: Southmost RWA
## Cost of recycling

Table 3.2 Wastewater Treatment Cost for Major Industrial and Domestic Sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Treatment cost (yuan/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal mining and washing</td>
<td>2.00</td>
</tr>
<tr>
<td>Food processing</td>
<td>3.20</td>
</tr>
<tr>
<td>Food manufacturing</td>
<td>1.95</td>
</tr>
<tr>
<td>Beverage manufacturing</td>
<td>1.65</td>
</tr>
<tr>
<td>Textile manufacturing</td>
<td>2.50</td>
</tr>
<tr>
<td>Paper and paper products manufacturing</td>
<td>2.50</td>
</tr>
<tr>
<td>Raw chemical materials and products</td>
<td>3.70</td>
</tr>
<tr>
<td>Petrochemicals</td>
<td>3.80</td>
</tr>
<tr>
<td>Medicines manufacturing</td>
<td>1.90</td>
</tr>
<tr>
<td>Chemicals manufacturing</td>
<td>3.70</td>
</tr>
<tr>
<td>Chemical fibers manufacturing</td>
<td>2.80</td>
</tr>
<tr>
<td>Non-metallic mineral products</td>
<td>2.65</td>
</tr>
<tr>
<td>Iron and steel smelting and pressing</td>
<td>3.50</td>
</tr>
<tr>
<td>Power generation and heating</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Cost of treatment: 0.3-0.6 USD/m³
Construction Costs of Multi Stage Flash Desalination plant

- **MSF Plant**
  - Construction Cost US$1700/m$^3$/day output
  - Fresh water Cost 0.75 USD/m$^3$
  - Uses water from power plant using 6,000 m$^3$/day costing 0.35 USD/m$^3$
  - Desalination costs kept down by using steam from the power plant
Other Issues

- Problem: pre-treatment – If the sea is polluted cost of pre-treatment is high

- Cost of Pre-treatment (Steam distillation vs. Reverse Osmosis)
  - Partly overcome by chemical by-products (c.f. Dead Sea Works)

- State Oceanic Administration (SOA) and brine

- Linkages between water supply under MWR and SOA

- In 2006 market US$55-70m in 2006 and should reach US$600-860m in 2012-15
CONCENTRATE DISPOSAL
Concentrate Disposal Options

- Fate of concentrate is the biggest issue facing desalination:
  - Ocean: typically several miles offshore with diffusers (dilution)
  - Surface water, sewer, land application (dilution)
  - Evaporation pond
  - Deep well injection
  - Zero-discharge=Industrial re-use: chemical/plastic industry, beneficial use
Deep-Well Injection in Texas

- Regulated by Clean Water Act, Underground Injection Control, and state and local regulations (Title 30 of TAC)
- Class I Injection well applications are expensive and technically complex, but this is currently the only class allowed to accept desalination wastes
- Injection along with produced waters into Class II wells for pressure maintenance or for EOR could greatly simplify the process to the benefit of both desalination and oilfield operators
Surface Discharge

- Convenient from sea water plants with high volume of concentrate
- Inland surface water body and evaporation pond discharge requires permitting by state and local regulations (Title 30) and must observe Clean Water Act regulations
Question: Desalination energy costs high

Should one go in the direction of Desalination of seawater costing 5 RMB/m³

When recycling and cleaning of domestic sewage is only 0.8-1.0 RMB/m³; industrial polluted water 1.7-3.0 RMB/m³
Zero Discharge

- Maximize water recovery
- May improve public acceptance
- Can have high operational and investment costs: need to evaporate brine to dry products
- Cost can be offset by beneficial use of by-products (brine or specific salts)

Source: Geo-processors Limited PTY, AU
Precipitated Calcium Carbonate (PCC)
Desalination

Future Plans

(million m³/year)

- 2013: 600
- 2020: 720
- 2020: 55 (brackish water)

Current (2010)

(million m³/year)

- Ashkelon (2005): 110
- Palmachim (2007): 30
- Hadera (2010): 100
- Current Total: 240

Under construction

- Haifa: 30
- Ashdod: 45

Reverse Osmosis Cost

- 2002: 12 kwh/m³
- 2008: 3.2 kwh/m³

From Dr. Richard Hardiman, Truman centre for peace HUJI