Reverse Osmosis (RO) Desalination using Renewable Energy Sources

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Main desalination technologies

Introduction
Commercially available seawater desalination technologies all around the world

- Reverse Osmosis (RO), 65%
- Multi-stage Flash Distillation (MSF), 21%
- Multi-effect Distillation (MED), 7%
- Electrodialysis (ED), 3%
- Nanofiltration (NF), 2%
- Other, 2%
Comparison between the energy consumptions for the water desalination techniques.

<table>
<thead>
<tr>
<th>Properties</th>
<th>MSF</th>
<th>MED</th>
<th>MVC</th>
<th>TVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical unit size (m³/day)</td>
<td>50,000–70,000</td>
<td>5000–15,000</td>
<td>100–3000</td>
<td>10,000–30,000</td>
</tr>
<tr>
<td>Electrical energy consumption (kWh/m³)</td>
<td>2.5–5</td>
<td>2–2.5</td>
<td>7–12</td>
<td>1.8–1.6</td>
</tr>
<tr>
<td>Thermal energy consumption (MJ/m³)</td>
<td>190–282</td>
<td>145–230</td>
<td>None</td>
<td>227</td>
</tr>
<tr>
<td>Equivalent electrical to thermal energy</td>
<td>15.83–23.5</td>
<td>12.2–19.1</td>
<td>None</td>
<td>14.5</td>
</tr>
<tr>
<td>(kWh/m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total electricity consumption (kWh/m³)</td>
<td>19.58–27.25</td>
<td>14.45–21.35</td>
<td>7–12</td>
<td>16.26</td>
</tr>
<tr>
<td>Product water quality (ppm)</td>
<td>≈ 10</td>
<td>≈ 10</td>
<td>≈ 10</td>
<td>≈ 10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties</th>
<th>SWRO</th>
<th>BWRO</th>
<th>ED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical unit size (m³/day)</td>
<td>Up to 128,000</td>
<td>Up to 98,000</td>
<td>2–145,000</td>
</tr>
<tr>
<td>Electrical energy consumption (kWh/m³)</td>
<td>4–6 with energy recovery</td>
<td>1.5–2.5</td>
<td>2.64–5.5</td>
</tr>
<tr>
<td>Thermal energy consumption (MJ/m³)</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Equivalent electrical to thermal energy</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>(kWh/m³)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total electricity consumption (kWh/m³)</td>
<td>4–6</td>
<td>1.5–2.5</td>
<td>2.64–5.5, 0.7–2.5 at low TDS</td>
</tr>
<tr>
<td>Product water quality (ppm)</td>
<td>400–500</td>
<td>200–500</td>
<td>150–500</td>
</tr>
</tbody>
</table>
Water desalination capacity based on the technology and the type of renewable energy used.
When pressure is applied to the concentrated solution, the water molecules are forced through the semi-permeable membrane from concentrated solution to fresh water. The amount of pressure required depends on the salt concentration of the feed water. The more concentrated the feed water, the more pressure is required to overcome the osmotic pressure.
Basics of Reverse Osmosis

As the feed water enters the RO membrane under pressure (enough pressure to overcome osmotic pressure) the water molecules pass through the semi-permeable membrane and the salts and other contaminants are not allowed to pass and are discharged through the concentrate stream, which goes to drain or can be fed back into the feed water supply in some circumstances to be recycled through the RO system to save water. The water that makes it through the RO membrane is called permeate or product water and usually has around 95% to 99% of the dissolved salts removed from it.
The main function of an energy recovery device would be to improve energy efficiency by harnessing spent energy from the reject and delivering it back to the feed, which are classified as follows:

- Hydraulic to mechanical-assisted pumping
- Hydraulically driven pumping in series
- Hydraulically driven pumping in parallel
Basics of Reverse Osmosis

Energy recovery device

➢ hydraulic to mechanical-assisted pumping
Basics of Reverse Osmosis

Energy recovery device

➢ hydraulically driven pumping in series

Diagram showing the process flow of a reverse osmosis system with energy recovery, including high pressure pump, membranes, and turbocharger.
Basics of Reverse Osmosis

Energy recovery device

- hydraulically driven pumping in parallel
Photovoltaic powered RO desalination

A schematic representation of a PV-RO system
Renewable Energy Sources for RO Desalination

- Photovoltaic powered RO desalination

Basic design model of a RO water desalination system powered by PV.
Energy requirements in renewable energy (Photovoltaic) driven RO desalination systems

<table>
<thead>
<tr>
<th>Technology variants</th>
<th>PV/RO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development status</td>
<td>Appl./R&amp;D</td>
</tr>
<tr>
<td>Energy input, kWh$_e$/m$^3$</td>
<td>0.5–1.5 BW, 4.0–5.0 SW</td>
</tr>
<tr>
<td>Typical current capacity, m$^3$/day</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Production cost, USD/m$^3$</td>
<td>6.5–9.1 BW, 11.7–15.6 SW</td>
</tr>
</tbody>
</table>

SW: Seawater, BW: Brackish Water
Wind energy powered RO desalination

Schematic representation of a typical wind-RO desalination system.
Wind energy powered RO desalination

Energy requirements in renewable energy (Wind energy) driven desalination systems

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<td>Energy input, kWhₑ/ m³</td>
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<td>Production cost, USD/m³</td>
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Hybrid PV-wind coupled RO desalination

Schematic of a typical small hybrid solar-wind-powered desalination plant.
Hybrid PV-wind coupled RO desalination
Solar thermal Rankine RO unit with energy recovery

Schematic diagram shows the operating principals of Rankine RO unit with energy recovery
Renewable Energy Sources for RO Desalination

Solar thermal Rankine RO unit with energy recovery

Schematic diagram shows the operating principals of Rankine RO unit with energy recovery
Renewable Energy Sources for RO Desalination

Solar thermal energy coupled RO unit

Schematic diagram shows the solar water collector coupled RO desalination unit
Renewable Energy Sources for RO Desalination

Concentrating solar power (CSP) system integrated with MED–RO hybrid desalination

Double scheme for power and fresh water production
Renewable Energy Sources for RO Desalination

Geothermal energy powered desalination plant

Schematic representation of a geothermal energy powered desalination plant
Combination of geothermal driven dual fluid organic Rankine cycle (ORC), proton exchange membrane (PEM) and reverse osmosis (RO) desalination unit.
Nuclear desalination coupling with RO

Schematic representation of nuclear power plant powered RO desalination plant
In this study, a biomass-based solid oxide fuel cell integrated with a gas turbine, a reverse osmosis desalination unit, and double-effect absorption chiller is proposed for power generation, cooling and freshwater production.
Wave energy converter system powered RO seawater desalination
Application of nanofluid for desalination system
Application of nanofluid for desalination system

Enhancement of energy utilization using nanofluid in solar powered membrane distillation

The nanofluid enhanced solar-powered membrane distillation represents a promising perspective for better solar energy utilization.
Energy storage systems for RO desalination unit
Desalination technologies coupled with renewable energy and storage systems.
Energy storage systems for RO desalination unit

➢ Fuel cell as an effective energy storage in reverse osmosis desalination plant powered by photovoltaic system

The system consists of PV array, self-charging fuel cell, electrolyzer, power conditioning unit (PCU) and hydrogen storage tank.
Energy storage systems for RO desalination unit

➢ Energy storage for desalination processes powered by renewable energy and waste heat sources

Thermal energy storage (TES) requires a suitable medium for storage and circulation while the photovoltaic/wind generated electricity needs to be stored in batteries for later use.
Conclusions

➢ The PV energy based desalination systems in use are available in different sizes ranging from 0.8 m$^3$/d to 60,000 m$^3$/d with an approximate cost of US$ 6.5/m$^3$ to 15.7/m$^3$.

➢ Wind energy based desalination plants are available in sizes ranging from 1 m$^3$/d to 250,000 m$^3$/d with an approximate cost of US$ 3.9/m$^3$ to 9.1/m$^3$.

➢ Desalination systems based on wind-PV hybrid energy have been implemented in many countries with the size ranging from 3 m$^3$/d to 83,000 m$^3$/d. The cost of water from systems varies from US$ 6.12/m$^3$ to 1.4 $/m^3$.

➢ Tidal energy-RO desalination using hydraulic turbine could reduce water desalination cost by 31%–41.7% compared with conventional RO system at the optimum feed pressure (5.6 MPa) and at water recovery rate of 40%.
Recommendations for future work

- Energy storage systems need to be integrated with intermittent renewable energy sources such as wind, solar and the ocean to smooth the power fluctuations caused by the intermittence.

- The existing storage systems, such as batteries, resulting in higher water desalination costs due to their short operation life and high cost. Therefore, economical, long-lasting energy storage solutions are needed.

- The geothermal energy, where available, could be used to eliminate the need for energy storage and to provide continuous energy during the periods of intermittence.
Recommendations for future work

➢ More research on optimization of hybrid energy sources-desalination systems is needed to identify methods that can minimize the cost of fresh water production.

➢ More research on study the effect of nanofluid on the performance of RO desalination system.

➢ More research on study the effect of lattent storage materials on the performance of RO desalination system.
The End