Feasibility of Produced Water Treatment and Beneficial Use in Permian Basin - Technology Assessment and Decision Support Tool

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Produced Water Treatment and Reuse

Decision-making process: multiple criteria, functions and objectives

- Produced water characteristics and beneficial use requirements
- Spatial analysis: wells, end users, water quality & quantity, conveyance system, centralized or clustered facilities
- Treatment technologies: meet reuse requirements
  - Robustness and maintenance: reduce labor and supervision requirement
  - Flexibility: mobile, able to handle high variation in water quality and quantity
  - Modular: small footprint and minimal environmental disturbance
- Waste management and disposal
- Cost benefits analysis
- Environmental impacts
Overview the Decision Support Tool (DST)

Water Quality Module
- Feed & Target water quality
- 76 parameters
  - Bulk
  - Salts
  - Radioactive
  - Organic

User & Expert Ranking Module
- A list of criteria
- Weights, expert ranking

Economic and Energy Demand Module
- Treatment cost
- Energy requirement

Treatment Selection Module [Optimization module]
- Treatment train
- Cost Estimates, energy demand

Selects the best treatment train with respect to technical & economic criteria while meeting water quality requirements.
Review identified 67 fundamental treatment technologies and integrated systems/processes

- Commercial status of technology
- Feed and product water quality
- Removal efficiencies
- Water recovery
- Infrastructure considerations
- Energy consumption
- Chemical demand
- Life cycle
- O&M considerations
Treatment selection model includes 67 pre-treatment, desalination and post treatment technologies

<table>
<thead>
<tr>
<th>Pretreatment</th>
<th>Adsorption</th>
<th>Advanced pretreatment</th>
<th>Biological</th>
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</thead>
<tbody>
<tr>
<td><strong>Basic Separation</strong></td>
<td>• Settling</td>
<td>• Activated carbon</td>
<td>• Activated sludge</td>
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<tr>
<td></td>
<td>• Coagulation</td>
<td>• Zeolite</td>
<td>• MBR</td>
</tr>
<tr>
<td></td>
<td>• Hydrocyclone</td>
<td>• Ion exchange</td>
<td>• BAF</td>
</tr>
<tr>
<td><strong>Adsorption</strong></td>
<td>• Activated carbon</td>
<td>• Chemical oxidation</td>
<td>• SBR-MBR</td>
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<tr>
<td></td>
<td>• Zeolite</td>
<td>• Microfiltration</td>
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</tr>
<tr>
<td></td>
<td>• Ion exchange</td>
<td>• Ultrafiltration</td>
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</tr>
<tr>
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<td>• Ultrafiltration</td>
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![Images of treatment processes]
Desalination Technologies

Membrane Separations

High Pressure Membrane
- Reverse osmosis
- Nanofiltration

Electrically Driven Processes
- Electrodialysis
- Electrodionization

Novel Membrane Processes
- Membrane distillation
- Forward osmosis

Thermal Technologies
- Thermal Distillation
- Dewvaporation
- multi-effect distillation (MED)
- mechanical vapor compression (MVC)
- Thermal vapor compression (TVC)
- multi-effect flush distillation (MSF)

Post Treatment
- pH adjustment
- SAR adjustment

Brine Management
- Evaporation basins
- Injection wells
- Crystallizer
Graphic User Interface (GUI)
User interaction - Output viewing options

<table>
<thead>
<tr>
<th>CTP</th>
<th>Acid Cation IX (H)</th>
<th>Media filter</th>
<th>Tight NF</th>
<th>Chemical disinfection</th>
<th>Evap ponds/ Brine disposal</th>
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<td>Ar stripping</td>
<td>(Ba) precipitation</td>
<td>Media filter</td>
<td>ED</td>
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<thead>
<tr>
<th>CTP</th>
<th>Capital Cost Total</th>
<th>Annualized Capital Cost ($)</th>
<th>Total Annual O &amp; M cost ($)</th>
<th>Total annualized cost ($)</th>
<th>Annual O &amp; M ($/gal)</th>
<th>Tot. ann</th>
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</thead>
<tbody>
<tr>
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<td>25,178,700</td>
<td>2,907,400</td>
<td>1,156,700</td>
<td>4,064,100</td>
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</table>

Constituents requiring treatment:

- Benzene
- Chloride
- Fluoride
- Iron (II)
- Manganese
- Rd 226+228+
- TDS (calc)
- Toluene
Case Study Scenarios

► **Agricultural Irrigation**
  - TDS ~ 1,500 mg/L

► **Hydraulic Fracturing**
  - Cross link gel system
  - Slickwater system TDS ~ 40,000 mg/L

► **Pecos River Augmentation**
  - TDS ~ 5,000 mg/L

► **Mining Activities**
  - Potash mining
Agricultural Irrigation

- Based on GIS mapping
- Based on 6-mile grid maps, chose the grid with lower salinity and close to irrigation areas
  - Eliminated wells with TDS over 40,000 mg/L
- 983 active oil and gas wells included in the cluster
- Annual produced water production: ~170 million bbls
- Average distance to irrigation areas: 1.9 miles
## Agricultural Irrigation

### Irrigation Water Quality Requirements

<table>
<thead>
<tr>
<th>Constituents (mg/L)</th>
<th>Crop Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>5</td>
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<tr>
<td>Arsenic (III)</td>
<td>0.1</td>
</tr>
<tr>
<td>Arsenic (V)</td>
<td>0.1</td>
</tr>
<tr>
<td>Chloride</td>
<td>70</td>
</tr>
<tr>
<td>Chromium, total</td>
<td>0.1</td>
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<tr>
<td>Copper</td>
<td>1.3</td>
</tr>
<tr>
<td>Fluoride</td>
<td>1</td>
</tr>
<tr>
<td>Iron (II)</td>
<td>5</td>
</tr>
<tr>
<td>Iron (III)</td>
<td>5</td>
</tr>
<tr>
<td>Lead</td>
<td>5</td>
</tr>
<tr>
<td>Lithium</td>
<td>15</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.2</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.2</td>
</tr>
<tr>
<td>Selenate</td>
<td>0.02</td>
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<tr>
<td>TDS</td>
<td>1,500</td>
</tr>
<tr>
<td>Total Suspended</td>
<td>30</td>
</tr>
<tr>
<td>Solids (TSS)</td>
<td>30</td>
</tr>
<tr>
<td>Total solids</td>
<td>30</td>
</tr>
</tbody>
</table>

### Produced Water Quality

<table>
<thead>
<tr>
<th>Parameter (mg/L)</th>
<th>Mean Value</th>
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<tbody>
<tr>
<td>pH</td>
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<tr>
<td>TDS</td>
<td>39,050</td>
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<tr>
<td>Sodium</td>
<td>27,590</td>
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<tr>
<td>Calcium</td>
<td>2,272</td>
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<tr>
<td>Magnesium</td>
<td>1,449</td>
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<tr>
<td>Chloride</td>
<td>23,323</td>
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<tr>
<td>Bicarbonate</td>
<td>1,246</td>
</tr>
<tr>
<td>Sulfate</td>
<td>1,482</td>
</tr>
</tbody>
</table>
### Agricultural Irrigation

<table>
<thead>
<tr>
<th>Treatment Technology</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Precipitation and Media Filtration</td>
<td>Oil and grease, particles</td>
</tr>
<tr>
<td>Chemical Softening</td>
<td>Hardness</td>
</tr>
<tr>
<td>Seawater Reverse Osmosis (SWRO)</td>
<td>Salinity</td>
</tr>
<tr>
<td>pH adjustment</td>
<td>Product water stabilization</td>
</tr>
<tr>
<td>Waste Disposal</td>
<td>Waste brine</td>
</tr>
</tbody>
</table>
Produced Water

Pre-treatment
- Removal of:
  - TSS
  - Organics
  - Hardness

Deep Well Injection

Treatment/Desalination
- TDS Bins (mg/L)
  - < 8,000
  - 8,000 – 40,000
  - 40,000 – 70,000
  - > 70,000

Benefits
- Mature, less costly, existing technology
  - RO/NF
  - ED/EDR
- Mature, cost intensive, existing technology
  - SWRO
  - BWRO
- Moderate mature, moderate costly technology
  - MVC
  - MED
- Emerging, cost intensive technology
  - FO
  - MD

Beneficial Use
- Reuse for hydraulic fracturing (No desalination required)
- Reuse for other purposes (potable use, aquifer recharge, irrigation, industrial, etc.)
- Recovery of valuable products and energy (I₂, NaCl, NH₄Cl, MgCl₂, Na₂CO₃, etc.)

Waste Disposal
Summary

► Produced water could be a reliable drought proof alternative water supply

► Site specific conditions and produced water quality & quantity dictate the technologies most suitable for implementation

► Integrated decision support tool with spatial analysis can assist in studying the feasibility of produced water treatment and economics of beneficial use

► Because of the complex of decision making process, field testing needs to be conducted to investigate the regulatory, institutional, technical and economic aspects of produced water treatment and reuse.
Thank you!

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