Use of Produced Water from the Illinois Basin by Coal-Based Power Plants

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Water/Energy sustainability symposium
2010 GWPC Annual Forum
Sep 26-29, 2010
Pittsburgh, PA
Water Usage in a Coal Power Plant

- Water streams in power plants
  - cooling water
  - steam turbines
  - flue gas desulphurization (FGD)
- Future developments in IL basin
  - more recirculated water cooling systems
  - CO₂ capture ???

Water withdrawals (MGD)
- once through cooling: 240 - 600
- recirculating: 4-7

~ 120 power plants in IL basin
- EIA predicts ~15% increase in power demand in U.S. and Illinois by 2030
- 25-80% increase in Illinois thermoelectric water consumption by 2030 (14-25% increase in U.S.)
- Significant increase in thermoelectric water consumption with CO₂ capture
## Produced Water Sources in IL Basin

### IL basin coal production (USGS)

![Graph showing IL basin coal production over time](https://example.com/graph.png)

### IL oil production (ISGS)

![Graph showing IL oil production over time](https://example.com/graph.png)

<table>
<thead>
<tr>
<th>Source</th>
<th>Current fate of water</th>
<th>Current flow rate (MGD)</th>
<th>With Carbon seq., flow rate (MGD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>Reinjected or disposed in subsurface</td>
<td>30-50</td>
<td>4 - 30</td>
</tr>
<tr>
<td>Coal</td>
<td>Discharged to surface</td>
<td>&lt; 1</td>
<td>No change</td>
</tr>
<tr>
<td>CBM</td>
<td>Discharged to surface or subsurface</td>
<td>&lt; 1</td>
<td>40</td>
</tr>
</tbody>
</table>

500 MW coal power plant, recirc. cooling water: 7 MGD
### Produced Water Sampling

<table>
<thead>
<tr>
<th>Site</th>
<th>Site Type</th>
<th>Site Name</th>
<th>Location</th>
<th># Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oil Field</td>
<td>Main Consolidated</td>
<td>Crawford, IL</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Oil Field</td>
<td>Union Bowman</td>
<td>Gibson, IN</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Oil Field</td>
<td>Louden</td>
<td>Fayette, IL</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Oil Field</td>
<td>Dale</td>
<td>Hamilton, IL</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Oil Field</td>
<td>Sugar Creek</td>
<td>Hopkins, KY</td>
<td>1</td>
</tr>
<tr>
<td>6a</td>
<td>Coal Mine</td>
<td>Galatia</td>
<td>Saline, IL</td>
<td>2</td>
</tr>
<tr>
<td>6b</td>
<td>Coal Mine</td>
<td>Millenium</td>
<td>Saline, IL</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Oil Field</td>
<td>Pattiki</td>
<td>White, IL</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Oil Field</td>
<td>Royal Falcon</td>
<td>Franklin, IL</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>CBM</td>
<td>ACT</td>
<td>Posey, IN</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Oil Field</td>
<td>Pioneer</td>
<td>Crawford, IL</td>
<td>3</td>
</tr>
<tr>
<td>11</td>
<td>Oil Field</td>
<td>Pulse Energy</td>
<td>Sullivan, IN</td>
<td>3</td>
</tr>
</tbody>
</table>
IL Basin Produced Water Quality

<table>
<thead>
<tr>
<th>Source</th>
<th>pH</th>
<th>TOC</th>
<th>TDS</th>
<th>Na</th>
<th>Ca</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Consolidated</td>
<td>7.0</td>
<td>510</td>
<td>19,000</td>
<td>7100</td>
<td>200</td>
<td>10400</td>
</tr>
<tr>
<td>Louden</td>
<td>7.4</td>
<td>9</td>
<td>102,000</td>
<td>33600</td>
<td>2600</td>
<td>60300</td>
</tr>
<tr>
<td>Dale</td>
<td>6.7</td>
<td>20</td>
<td>127,000</td>
<td>39000</td>
<td>4900</td>
<td>74900</td>
</tr>
<tr>
<td>Sugar Creek</td>
<td>6.4</td>
<td>15</td>
<td>25,000</td>
<td>8000</td>
<td>600</td>
<td>14000</td>
</tr>
<tr>
<td>ACT</td>
<td>7.5</td>
<td>7</td>
<td>25,000</td>
<td>7200</td>
<td>120</td>
<td>10400</td>
</tr>
<tr>
<td>Pioneer</td>
<td>7.2</td>
<td>2</td>
<td>27,700</td>
<td>10600</td>
<td>160</td>
<td>16000</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>8.8</td>
<td>0.4</td>
<td>1,960</td>
<td>750</td>
<td>3</td>
<td>140</td>
</tr>
<tr>
<td>Galatia</td>
<td>7.9</td>
<td>8</td>
<td>17,980</td>
<td>6300</td>
<td>270</td>
<td>9500</td>
</tr>
<tr>
<td>Millenium</td>
<td>7.6</td>
<td>15</td>
<td>16,000</td>
<td>5800</td>
<td>170</td>
<td>8200</td>
</tr>
<tr>
<td>Pattiki</td>
<td>7.5</td>
<td>1</td>
<td>20,400</td>
<td>7200</td>
<td>230</td>
<td>10800</td>
</tr>
<tr>
<td>Royal Falcon</td>
<td>8.1</td>
<td>0.5</td>
<td>520</td>
<td>48</td>
<td>80</td>
<td>21</td>
</tr>
</tbody>
</table>

Previous ISGS studies (1952 and 1998) of oil produced water

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>TDS</th>
<th>Na</th>
<th>Ca</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>6.6</td>
<td>110,000</td>
<td>37,000</td>
<td>4,300</td>
<td>68,000</td>
</tr>
<tr>
<td>Std dev</td>
<td>0.6</td>
<td>34,000</td>
<td>11,000</td>
<td>2,600</td>
<td>21,000</td>
</tr>
</tbody>
</table>
Water Treatment Objectives and Costs

• Water treatment objectives plant dependent
  – current water
  – cooling system materials
    • corrosion, scaling, pitting

• PW treatment costs

<table>
<thead>
<tr>
<th>Item</th>
<th>$ / 1000 gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>subsurface disposal</td>
<td>10 - 20</td>
</tr>
<tr>
<td>treatment</td>
<td>TBD (&gt;= 4)</td>
</tr>
<tr>
<td>transport</td>
<td>TBD (1 - 60?)</td>
</tr>
<tr>
<td>salt harvesting?</td>
<td>3 - 30</td>
</tr>
<tr>
<td>total</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Key components:
TDS, TOC, Ca, Si, Cl, NH$_3$, SO$_4$

• Current PW water costs
  – multiple sites use surface discharge
  – for oil fields, water re-injected to maintain reservoir pressure

Sea water desal: $4 per 1000 gal
IL municipal water: $4 per 1000 gal
Some power plants pay ~$0
Bench-scale Water Treatment

**Filtration:**
- sand
- walnut shell
- anthracite

**Adsorption:**
- organoclay
- activated carbon

**Ion Exchange:**
- antiscalants
- pH adjustment

**Reverse Osmosis**

- **RO system**
  - Sepa cross flow holder, area = 139 cm²
  - recirculated water (both permeate and concentrate)
  - membranes compacted with NaCl for 24 hours
Louden oil
TDS = 102,000 mg/L
DOC = 9 mg/L

Main consolidated oil
TDS = 19,000 mg/L
DOC = 500 mg/L
# Bench-scale predictions and results

**Dow's ROSA predicted performance for Main Consolidated Oil: TDS = 19,000 mg/L**

<table>
<thead>
<tr>
<th>Membrane</th>
<th>Operating Pressure (psi)</th>
<th>Salt Rejection (%)</th>
<th>Permeate Flux (L/m²-h-psi)</th>
<th>Permeate TDS (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW30HR</td>
<td>1000</td>
<td>99.8</td>
<td>0.04</td>
<td>47</td>
</tr>
<tr>
<td>XLE</td>
<td>400</td>
<td>97.5</td>
<td>0.09</td>
<td>410</td>
</tr>
<tr>
<td>NF90</td>
<td>400</td>
<td>94.7</td>
<td>0.11</td>
<td>1030</td>
</tr>
</tbody>
</table>

**Graphs:**

- **SW30HR, 940 psi**
- **NF90, 600 psi**
Membrane fouling and pretreatment

- NaCl solution replaced every 24 h
- XLE membrane, 940 psi
- 15% flux decline at 24 h, then flat

Main Consolidated Oil

XLE membrane: GAC pre-treatment is better
TFC XR: microfiltration is better

Fouling caused by scaling or organics not removed by GAC
Additional oil and CBM PW membrane results

**Louden Oil:** TDS = 102,000 mg/L

Osmotic pressure ~ 1200 psi

TFC HR membrane at 1000 psi: 
~60% salt rejection

**ACT Coal bed methane:** TDS = 25,000 mg/L

XLE at 940 psi, 30% flux decrease at 24 hours

TFC XR at 940 psi, 32% flux decrease at 24 hours
Conclusions

- IL basin has significant produced water, likely increasing in future
- produced water from brackish to extremely salty
- membranes can treat water with TDS < 55,000 ppm
  - pretreatment optimized for each source
- motivation needed to use produced water
  - water scarcity (climate change?)
  - new regulations for produced water disposal
Acknowledgements

• Funding organizations
  – U.S. Department of Energy, National Energy Technology Laboratory (Cooperative Agreement DE-NT0005343)
  – Illinois Department of Commerce and Economic Opportunity through the Office of Coal Development and the Illinois Clean Coal Institute (Grant 08-1/US-3)
    – *This presentation does not necessarily reflect their views*
• Several staff members from Coal and Oil & Gas Sections of the Illinois State Geological Survey for their help in the collection of the information/maps