Cost Effective Recovery of Low-TDS Frac Flowback Water for Re-use

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GWPC, Water Issues (And Solutions) Associated with Hydraulic Fracturing
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Outline

• Scope, Benefits & Challenges
• Frac flowback water characteristics – variation
• Key Contaminants
• “Product water” requirements
• Treatment process options
• Recovery process value assessment
• Conclusions
Scope: Low-TDS flowback water recovery for re-use in fracking

Conventional Disposal

Well head → Proppant → Gas for sales

Interim Flowback Water Storage

C_{Transport} \sim \$1-10/bbl

C_{UIC} \sim \$1-3/bbl

C_{Disposal} = C_{Transport} + C_{UIC}

Flowback Water Recovery Process

Well head → Proppant → Gas for sales

Interim Flowback Water Storage

Flowback Water Recovery Process

“product”

High TDS reject

C_{UIC}

C_{Delivery}

Controllable water site

Benefits:
- Reduced net fresh water used in hydrofracturing process
- Reduced wastewater and associated disposal costs

Challenges:
- Technical/economical feasibility of mobile rig configuration
- Applicability across geographic locations – varying composition and frac re-use specifications
- Controllability & robustness – varying flowrates & compositions
## Frac Flowback: TDS ranges for various shales

Modern Shale Gas Development in the United States: A Primer, April, 2009, Prepared for US DOE, All Consulting, Tulsa, OK

**Total Dissolved Solids (TDS), mg/L**

**Shale** | **Average TDS, ppm** | **Maximum TDS, ppm** | **Applicability to Low-TDS recovery**
--- | --- | --- | ---
Fayetteville | 13K | 20K | ~100%
Woodford | 30K | 40K | ~100%
Barnett | 80K | >150K | ~25%*
Marcellus | 120K | >280K | ~10%*

* early flowback only

Suitability for recovery via RO membranes: < 45,000 ppm TDS
Frac Flowback: Flow rates & TDS

Frac Water Usage
Dependent upon:
- Type of well
- Geographical location
- Operator bias/experience:

<table>
<thead>
<tr>
<th>Well type</th>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>11,000 – 90,000 bbls</td>
<td>40,000 bbls</td>
</tr>
<tr>
<td>Horizontal</td>
<td>70,000 – 190,000 bbls</td>
<td>100,000 bbls</td>
</tr>
</tbody>
</table>

Typical flow rates vs. flowback time

<table>
<thead>
<tr>
<th>Time</th>
<th>Flowback rate</th>
<th>Flowback recovery, % frac fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5 days</td>
<td>100-150 bbl/hr</td>
<td>10~ 25%</td>
</tr>
<tr>
<td>5-15 days</td>
<td>20 – 60 bbl/hr</td>
<td>8 ~ 12%</td>
</tr>
<tr>
<td>15-30 days</td>
<td>5-10 bbl/hr</td>
<td>1~5%</td>
</tr>
<tr>
<td>30 - 90 days</td>
<td>10 bbl/day</td>
<td>1~2%</td>
</tr>
</tbody>
</table>

%flowback after 90 days: 25~40%*
*could be higher in certain wells

Caveat: “Every well is different”
Frac Flowback: Key Contaminants

Impact for re-use

Plugging

Fluid stability

Scaling

Bacterial growth

Radioactivity

Particulates
Suspended solids
Oil and grease
Dissolved Organics
Volatile Organics
Total Dissolved Solids (TDS)
Chlorides
Iron
Hardness (Ca, Mg)
Barium
Strontium
Silica
Sulfates
Biological counts
NORM (Normally Occurring Radioactive Materials)
Frac Flowback Water Sampling

Woodford Shale Site Days 1-14

Marcellus Shale Site Days 1-8

Appearance changes with time
Flowback samples from Woodford sites
Site-1 (Days 1-14) & Site-2 (Day 26)

Challenge: Composition highly variable with time
...and location - geology, operating conditions
Frac Flowback Recovery Process

Process options for mobile rig

Option 1
- Clarify only (for frac re-use)
- Solid waste for disposal
- To Disposal

Option 2
- Soften
- Ba, Sr, Ca, Mg, Fe, Sulfates
- Softened (for frac re-use)
- Concentrate

Option 3
- Desal
- Desalinated (for frac re-use)
- Concentrate
- <500 ppmTDS for surface discharge

Product options

Flowback water

Solid waste for disposal

Requirements:
- Minimum cost for use application
- Maximum recovery
- Robust operations for variable feed
- “Green” process with minimal chemicals use

*Organics removal to avoid bacterial growth during water storage

**NORM removal depends on site
Requirements for the “product” waters

* Best available specifications from few operators and published literature. Actual values may vary depending on shale formation, local regulations and operator preferences.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Conventional &quot;fresh&quot; source water before additive blending</th>
<th>Conventional frac fluid after additive blending</th>
<th>&quot;Clarified product&quot; for re-use</th>
<th>&quot;Softened product&quot; for re-use</th>
<th>&quot;Desal water&quot; product for frac re-use</th>
<th>&quot;Desal water&quot; product for agricultural discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
<td>mg/L</td>
<td>&lt;500</td>
<td>&lt;1000</td>
<td>NR</td>
<td>NR</td>
<td>&lt;20,000</td>
<td>&lt;500</td>
</tr>
<tr>
<td>Total alkalinity</td>
<td>mg/L</td>
<td>~ 50</td>
<td>~50</td>
<td>&lt;600</td>
<td>&lt;600</td>
<td>&lt;600</td>
<td>~ 50</td>
</tr>
<tr>
<td>Hardness as CaCO3</td>
<td>mg/L</td>
<td>&lt;150</td>
<td>&lt;150</td>
<td>&lt;50</td>
<td>&lt;2000</td>
<td>&lt;2000</td>
<td>See SAR</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td>mg/L</td>
<td>&lt;2 ~ 10</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;2 ~ 10</td>
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<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>&lt;4</td>
<td>&lt;250</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/L</td>
<td>&lt;50</td>
<td>&lt;100</td>
<td>NR</td>
<td>NR</td>
<td>&lt;12,500</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Iron</td>
<td>mg/L</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;5</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Oil &amp; soluble organics</td>
<td>mg/L</td>
<td>&lt;10</td>
<td>&lt;400</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;29</td>
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<tr>
<td>Sulfate</td>
<td>mg/L</td>
<td>&lt;25</td>
<td>&lt;25</td>
<td>&lt;125</td>
<td>&lt;25</td>
<td>&lt;25</td>
<td>&lt;25</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>mg/L</td>
<td>~0.1</td>
<td>0.1 ~ 5</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Bacteria Count</td>
<td>#/100mL</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>&lt;100</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>6.7 - 7.4</td>
<td>5.2 - 8.9</td>
<td>6.5 - 8.5</td>
<td>6.5 - 8.5</td>
<td>6.5 - 8.5</td>
<td>6.7 - 7.4</td>
</tr>
<tr>
<td>SAR</td>
<td></td>
<td></td>
<td></td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>&lt;12</td>
</tr>
<tr>
<td>Temperature</td>
<td>C</td>
<td></td>
<td></td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>ambient</td>
</tr>
</tbody>
</table>

Product quality requirements dependent on shale location, operator preference and local/state regulations
Treatment process options

<table>
<thead>
<tr>
<th>Product options</th>
<th>Treatment Processes</th>
<th>Water recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarified only</td>
<td>Raw water (feed) → Clarifier → Product water</td>
<td>&gt;95%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solid Waste</td>
</tr>
<tr>
<td>Softened only</td>
<td>Raw water (feed) → Softener/Clarifier → Product water</td>
<td>&gt;95%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solid Waste</td>
</tr>
<tr>
<td>Desalinated</td>
<td>Raw water (feed) → Softener/Clarifier → Membrane</td>
<td>35-80%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Depending on product purity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reject water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solid Waste</td>
</tr>
</tbody>
</table>

Increasing process complexity adds costs
Membrane desalination

Recovery for 30,000 - 45,000 ppm TDS feed:

- 50-80% for a 20,000 ppm TDS product
- 35-55% for a 250 ppm TDS product

Reverse Osmosis rig

- Feed
- Product
- Reject

70,000 ppm TDS

Recovery limited by osmotic pressure & membrane fouling

Water recovery vs. Flowback TDS

Seawater desalination

Flowback range applicable for "Low-TDS" recovery process

X, fractional flowback recovery

TDS in Flowback, ppm

Product TDS, ppm

- 250
- 10,000
- 20,000

- 0%
- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- 70%
- 80%
- 90%
- 100%

- [-10,000, 20,000, 30,000, 40,000, 50,000, 60,000, 70,000, 80,000]
System cost analysis

Flowback Water Recovery Process

Conventional Disposal

\[ C_{\text{Conventional}} = F \times C_{\text{Disposal}} \] $/bbl frac water

\[ C_{\text{Disposal}} = C_{\text{Transport}} + C_{\text{UIC}} \] $/bbl disposed water

FWRP

\[ C_{\text{FWRP}} = x \times F \times C_{\text{Product}} + (1-x) \times F \times C_{\text{Disposal}} \] $/bbl frac water

\[ X = \frac{F_{\text{Product}}}{F}, \quad \text{Fractional water recovery} \]

\[ C_{\text{Product}} = C_{\text{Treatment}} + C_{\text{Delivery}} - C_{\text{Fresh Water}} \] $/bbl Product Water

Key parameters:

- \( X \), fractional water recovery
- \( C_{\text{Product}} \) (Treatment + Delivery)
- \( C_{\text{Disposal}} \) (Transport + UIC)

Key objective:

Minimize \( C_{\text{FWRP}}/C_{\text{Conventional}} \)
Value Assessment for Flowback Recovery

CASE: Desired product: TDS <20,000 ppm

Examples:

Site A: Flowback TDS = 45,000 ppm
- Product recovery, \( x = 50\% \)
- \( C_{\text{Product}} = $2/bbl \) Product water
- \( C_{\text{Disposal}} = $4/bbl \) Disposed water
- \( C_{\text{FWRP}} = 75\% C_{\text{conventional}} \) \( \Rightarrow \) 25% savings

Site B: Flowback TDS = 35,000 ppm
- Product recovery, \( x = 70\% \)
- \( C_{\text{Product}} = $1/bbl \) Product water
- \( C_{\text{Disposal}} = $2.50/bbl \) Disposed water
- \( C_{\text{FWRP}} = 60\% C_{\text{conventional}} \) \( \Rightarrow \) 40% savings
Value Assessment for Flowback Recovery

CASE: Desired product TDS < 500 ppm

Examples:

**Site A:**
- Flowback TDS = 45,000 ppm
  - Product recovery, x = 37%
- $C_{Product} = $2/bbl Product water
- $C_{Disposal} = $4/bbl Disposed water
  - $C_{FWRP} = 82\% \ C_{conventional} \Rightarrow 18\% \ savings$

**Site B:**
- Flowback TDS = 35,000 ppm
  - Product recovery, x = 51%
- $C_{Product} = $1/bbl Product water
- $C_{Disposal} = $2.50/bbl Disposed water
  - $C_{FWRP} = 70\% \ C_{conventional} \Rightarrow 30\% \ savings$
Summary and Conclusions

• Flowback water is not a uniform “raw material” from a process development perspective.
  - Flowback rates & composition vary considerably depending the geological formation, and operating conditions (e.g. chemicals introduced during the drilling and fracturing operations).
  - Flowback volume and water properties vary throughout the lifetime of the well.
• Applicability of low-TDS (< 45,000 ppm) recovery approach is ~100% for Fayetteville and Woodford shales, while limited to very early flowback in Barnett, Marcellus and other shales.
• No clear consensus on product quality requirements for re-use in hydrofracturing.
• Parametric value assessment tool developed to assess system cost benefit relates sensitivity of water recovery via treatment processes employed, and product/reject disposal costs on overall economic attractiveness of any Flowback Water Recovery Process (FWRP) relative to conventional disposal. It is believed that this approach will provide a rational basis for treatment process selection appropriate to well flowback characteristics and local disposal costs & regulations.