Zero Discharge Water Management for Horizontal Shale Gas Well Development

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West Virginia University Water Research Institute
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West Virginia University, supported by FilterSure, Inc., was selected by the Department of Energy in 2009 to develop:

“Zero Discharge Water Management for Horizontal Shale Gas Well Development.”

The project is designed to be conducted in two phases, summarized as follows:
Background – Phase I

- Evaluate treatment options for recycling frac return water (FRW) at WVU research facilities.
  - Base system is the FilterSure filter, a 2-gpm Process Development Unit (PDU)
  - Evaluate pre- and/or post-filtration treatment options
  - Use real Marcellus Shale FRW
- Phase I ends with a decision to construct a prototype mobile unit

Dave Munyan, FilterSure operator
Following decision to proceed:

- Fabricate a mobile prototype unit (similar to unit shown at right)
- Conduct sustained test at an active field drilling site.
- Evaluate results

Apply the technology in commercial applications

Automated 30 US GPM Mobile Unit (7 m³/hr, 1000 bbl/day)
Phase I Industry Group

- Industry contact group assembled
  - Abarta Energy, Covalent Energy, Chesapeake Energy Corporation, Energy Corporation of America, Gastem USA, Marathon Oil Company, Range Resources, and Universal Well Services

- Industry group queried for basic frac procedures, general information, and frac water requirements
  - Outstanding industry response, providing valuable data.
  - Industry group provided FRW for testing at WVU as well as valuable advice on what would help them most.
Phase I Survey

- **Water requirements obtained from 6-page survey**
- **Information on volumes, storage, quality, transport**

<table>
<thead>
<tr>
<th>Well Information</th>
<th>a. Horizontal</th>
<th>b. Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Which state(s) are most of your wells drilled?</td>
<td>NY PA OH WV</td>
<td>NY PA OH WV</td>
</tr>
<tr>
<td>2. What is the approximate death range of Marcellus (100s of ft)?</td>
<td>1 1 2 3 4 5 6 7 8</td>
<td>1 1 2 3 4 5 6 7 8</td>
</tr>
<tr>
<td>3. What is a typical type of frac for your wells?</td>
<td>SLICKWATER HEAVY GEL FOAM OTHER</td>
<td>SLICKWATER HEAVY GEL FOAM OTHER</td>
</tr>
<tr>
<td>4. What is a typical size range of frac for your wells in gallons? (1000 gal = 1000 gal)</td>
<td>&lt; 1M 1 2 3 4 5 6 7 8 &gt; 1M</td>
<td>&lt; 40K 40 80 120 160 200 &gt; 200K</td>
</tr>
<tr>
<td>5. What is a typical number of frac stages for your wells?</td>
<td>1 2 3 4 5 6 7 8 9 &gt; 9</td>
<td>1 2 3 4 5 &gt; 5</td>
</tr>
<tr>
<td>6. What is a typical proppant program for any given stage?</td>
<td>EXCELLENT GOOD FAIR POOR</td>
<td>EXCELLENT GOOD FAIR POOR</td>
</tr>
<tr>
<td>7. Overall, how successful are your frac jobs?</td>
<td>EXCELLENT GOOD FAIR POOR</td>
<td>EXCELLENT GOOD FAIR POOR</td>
</tr>
<tr>
<td>8. Additional information on frac?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Phase I Survey Highlights

- Slickwater frac is dominant type of treatment
- Frac sizes for most horizontal wells range from 4 million to 6 million gallons (up to 10 stages) using as much as 250 tons of sand/stage.
- Vertical well fracs are similar in size to a single horizontal well stage, about 500,000+ gallons, usually in a single stage, with a total of 250 to 500 tons of sand.
Phase I Survey Highlights (cont.)

- Frac return water is \(\sim 10\) to \(20\%\) of the amount injected. After \(7 - 10\) days flow back is greatly reduced and is considered produced water.

- Flow-back rates during first \(7 - 14\) days may average \(3,000 - 5,000\) barrels/day, declining rapidly to a few \(100\) bbl/day. Further decline is gradual, \(10\) to \(20\) b/day, after a few months.

- Both horizontal and vertical wells are successful upon stimulation, but horizontal wells appear to provide better economics.
Phase I Survey Highlights (cont.)

- **Frac_water Requirements**
  - Chlorides < 70,000 mg/L
  - TDS <120,000 mg/L
  - With 5:1 makeup that would yield about 25,000 mg/L
  - TSS not defined
  - pH from 5.5 to 8.0
  - Multivalent ions – Should be limited but no specific cutoffs cited, except for Fe (<500 mg/L) and SO4 (<50 mg/L)
  - Bacteria < 10,000 counts (colonies/mL)
Recycling is Widely Practiced, Solves a Problem, but…

- Operators are concerned that untreated water may damage gas production.
  - Micro-fractures may become plugged with residual chemicals, precipitates, or shale fines.
  - Communication with reservoir may be reduced or lost entirely.

- Field Case Studies are Needed to Document Frac Treatment Effects on Gas Production.
  - These studies need to be done, but will take time to complete.
  - Water cleanup now will reduce/eliminate productivity concerns until definitive studies are completed.
Common Sense + Science

- Some Frac_waters are better than others
  - TSS should be low – don’t pump something that could plug the miniscule reservoir permeability
  - TDS is a potential problem, but focus on controlling sulfate, calcium, iron, magnesium, barium, and strontium
  - Solubility of scale-forming multivalent ions are pressure and temperature dependent. High pressure fracture treatment causes dynamic changes in both.
  - Eliminate bacteria.
Phase I Technical Approach

Develop and Test Treatment Methods

- WVU acquired and tested five frac water samples with TDS ranging from 10,000 – 185,000 mg/L
- Chemistry was determined, including radioactivity (none detected) and hardness (4,000 – 50,000 mg/L)
- Particle Size Distribution and Total Suspended Solids were used to select and sequence filter media

Electrocoagulation (EC) Followed By FilterSure Filtration Has Proven To Be Effective
Continuous Process Flow Demonstrated

Criteria after 5X dilution:
- Scale formers < 2,500 mg/L
- TDS < 50,000 mg/L
- Calcium < 250 mg/L
- Iron < 3.5 mg/L
- pH 6.5 to 7.5
Particle Size Distribution, Sample #3 & 3EC, Marcellus Shale Before and After Electrical Coagulation

Particle Size Distributions, pct

Particle Size Distribution, microns (logarithmic Scale)

PSD of Raw Water, before EC treatment
PSD of Water after EC Treatment

West Virginia University Water Research Institute
Crystal Clear Water Produced By EC And Filtration
Experimental results on two Marcellus frac return water samples

<table>
<thead>
<tr>
<th>Solute</th>
<th>Sample A, 40,000 ppm TDS</th>
<th>Sample B, 110,000 ppm TDS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw</td>
<td>Treated</td>
</tr>
<tr>
<td>Cl</td>
<td>17100</td>
<td>12600</td>
</tr>
<tr>
<td>Na</td>
<td>8530</td>
<td>4960</td>
</tr>
<tr>
<td>Ca</td>
<td>1610</td>
<td>1040</td>
</tr>
<tr>
<td>Sr</td>
<td>280</td>
<td>214</td>
</tr>
<tr>
<td>K</td>
<td>243</td>
<td>207</td>
</tr>
<tr>
<td>Mg</td>
<td>188</td>
<td>121</td>
</tr>
<tr>
<td>Ba</td>
<td>172</td>
<td>71</td>
</tr>
<tr>
<td>Fe</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>SO4</td>
<td>28</td>
<td>13</td>
</tr>
<tr>
<td>TDS</td>
<td>38700</td>
<td>26800</td>
</tr>
<tr>
<td>Hardness</td>
<td>4890</td>
<td>3960</td>
</tr>
<tr>
<td>pH</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>
# 33% Suspended Solids Removed

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Pre Treatment</th>
<th>Post Treatment</th>
<th>Net Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC</td>
<td>µS/cm</td>
<td>66,300</td>
<td>48,800</td>
<td>-26%</td>
</tr>
<tr>
<td>TDS</td>
<td>mg/L</td>
<td>38,700</td>
<td>26,800</td>
<td>-31%</td>
</tr>
<tr>
<td>Hardness</td>
<td>mg/L</td>
<td>4,890</td>
<td>3,960</td>
<td>-19%</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>7</td>
<td>8</td>
<td>7%</td>
</tr>
<tr>
<td>TSS</td>
<td>mg/L</td>
<td>99</td>
<td>66</td>
<td>-33%</td>
</tr>
</tbody>
</table>
Success Criteria for Moving to Phase II

1. Technical capability – will the technical design achieve target water quality?

2. Economics – will a commercial design have the potential to improve on cost of hauling and disposal of frac return water?
Prototype Mobile Unit
Major Components

Commercial 30-GPM Electro-Coagulation Unit

5th Generation FilterSure 30-GPM Unit

Access Hatch to Change Media, If Needed
FilterSure™ Technology Highlights

- Five chambers hold media increasing filter capacity by 400% over conventional filter
- Proprietary media carefully selected for Marcellus Shale testing program
- Manual operation at WVU but commercial unit will be automated
  - Automatic bypass valve
  - Automatic backwash
  - Low backwash volumes
  - Low pressure ops (30 psig)
Phase II

Finalize System Design and Determine Costs

The preliminary design of the MTU will be finalized, cost quotes obtained, vendors selected, and equipment ordered.

Fabricate Mobile Treatment Unit (MTU)

The MTU will be fabricated and subsystems integrated, including data acquisition instrumentation needed for remote monitoring of automatic operation of the unit in the field. The unit will be tested at the fabricators facility and problems fixed before shipment to the field.
Phase II (Cont.)

Install the Mobile Treatment Unit in the Field

The MTU will be installed at a producer location. Additional water storage may be needed, and will be coordinated with the producer’s plans for current and future drilling.

MTU Testing and Startup

Installed MTU will be inspected and determined ready for testing. Any problems will be fixed. Startup will be coordinated with producer.
Phase II Tasks (Cont.)

MTU Operations, Monitoring, Maintenance
On-site operations will last 2 - 4 months. Initially monitored by technicians, operations will transition to electronic monitoring. Maintenance schedules will be established.

MTU Decommissioning
MTU will be decommissioned at the end of the test plan period. Ownership will transfer to FilterSure who has guaranteed the industry cost-share for this effort.

MTU Demonstration Report
A formal and complete MTU demonstration report will document the Phase II activities.
Preliminary Capital Cost Estimates

• Major commercial cost elements reasonably well known:
  o 30 GPM electrocoagulation unit
  o 30 GPM FilterSure unit
  o Construction costs

• Economics remain favorable
Expected Impacts On Gas Industry

- Recycled water can be reused indefinitely
  - Suspended solids removed to 30 to 70 mg/L
  - Water meets or exceeds recycle requirements

- Eliminate leaching liability concerns
  - EC converts metals to complex flocs
  - Early testing shows that solids pass TCLP leach test
Expected Impacts On Gas Industry (Cont.)

- Less frac water to be hauled
- Zero frac water for disposal
- Lower roadway, traffic impacts
- Lower pollution from fugitive dust, engine exhaust, muddy streams
- Reduce regional water demand
Commercialization Schedule

• Complete Process Proof of Concept Demos
  o Early September 2010

• Reach Decision to Proceed
  o End September 2010

• Construct and Startup 30-GPM Mobile Unit
  o Spring 2011

• Complete DOE Contract
  o End September 2011
Summary

- Research ahead of planned schedule
- Batch testing of EC/FilterSure successful
- Continuous process demonstration successful
- Decision to proceed - end of September 2010
Summary (cont.)

• Prototype 30-GPM Mobile Unit
  o Designed, constructed, and in the field by Spring 2011
  o Operations proven by Summer 2011
  o Contract complete by end of September 2011

• Commercial 70-GPM Units
  o Could begin field operations by Fall of 2011