Hydraulic Fracturing

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Agenda

- Introduction
- Hydraulic Fracturing for Unconventionals (Shale, Tight Gas/Oil).
  - Which Fluid?
  - Which Design?
  - Which Completion?
- Microseismic Data for the Appraisal of Hydraulic Fracturing Treatments
  - Leveraging Spatial and Temporal Distributions
  - Stimulated Reservoir Volume
- Water Management, Waterless and less water Frac Fluids and Environmental Stewardship for HF
- Conclusions
Which fluid?

- Slickwater
- X-Link
- Hybrid
- Tailored for Shales
Conventional Tight Gas Fracturing

- Conventional Tight Gas Fracturing Uses Crosslinked Fluid Systems to Carry Proppant Deep into the Fracture

- Advantages
  - Easy on equipment
  - Good proppant transport
  - Low friction pressure
Slick Water Fracturing

- Slick Water Fracturing Uses Linear Gels or Water with Friction Reducer
- Advantages
  - Cheap
  - Quick fluid recovery
  - Operationally simple
- Slick Water Systems Have No Proppant Transport Capabilities, and Rely Purely on Turbulent Flow Effects to Carry the Proppant
- There is Evidence to Suggest that in Certain Formations, Low Viscosity Fluids will Produce Better Height Containment
Slick Water Fracturing

- Slick water fracturing works in very low permeability, relatively shallow formations
- Should not be used for:-
  - Medium to high density proppant systems
  - Permeability > +/- 0.01 md
  - High proppant concentrations
  - Formations which require full coverage of the fracture face
  - Higher closure stress wells
- Hybrid treatments use slick water to create the fracture, then use crosslinked fluids to carry the proppant
  - Good combination of technologies
Slick Water Fracturing

- Over-displacement
  - Slick water treatments are tolerant of over-displacement at the end of the job.
  - This means that they are very suited to the modern open hole multizone completion systems
    - Ball actuated
    - Ball placement within displacement not critical
  - Conventional or hybrid treatments MUST NOT BE OVERDISPLACED
    - Risk of having no proppant by the wellbore
  - This means that treatments requiring high strength proppants, or with proppant concentrations above +/- 1.5 ppg, are less suitable for open hole multi-zone completions
Mobility, a Critical Driving Parameter

What the reservoir needs

Planar Fractures

- Short High Conductivity Fractures
- Longer Less Conductive Fractures
- Ultra-high Surface area Fractures
- “Complex” Fractures

Size, complexity, cost of treatments increase

Equation:

\[ q \approx \frac{kh(P_{res} - P_{wf})}{u[\ln(r_e / r_w) + S]} \]
Natural Fractures System (Complex Frac Network)
The Perfect Shale?

- Slickwater fluids
  - Min. Sand Concentrations
  - Simul, Zipper Fracs

- Ductile-Anisotropic Shales
  - Hybrid fluids and or xlink fluids
  - Biwing frac

Brittle

Isotropic

Anisotropic

Ductile
Petrophysics: “Shales” have variable mineralogy…
Which Completion?

Plug-and-perf completion

Ball-activated completion

Coiled tubing-activated completion
Plug-and-Perf Completions
It’s More Complicated Than You Think

**INEFFECTIVE FRAC DESIGN**
- Can result in erratic proppant placement—resulting in an underperforming well and leaving reserves behind
- Can result in a screenout—increasing completion time by days and increasing costs significantly

**MULTIPLE SERVICES**
- Wireline, completions, pressure pumping, coiled tubing, milling services
- Operational efficiency and productivity highly dependent on each service working together effectively

**MULTIPLE SUPPLIERS**
- Complicate project planning, management and logistics
- Mixing and matching components can result in down time due to incompatibility

**LACK OF COLLABORATION**
- Leads to operational inefficiency, unnecessary cost, and unproductive stages
Baker Hughes’ IN-Tallic Frac Balls
Plug-and-Perf Market

Completion Components
Baker Hughes’ IN-Tallic Frac Balls
Shadow Plug Run History

- 132 total runs
  - 59 in Canada
  - 73 in Marcellus/Utica
  - 5 Different Operators
  - 9 Different Wells

- Over 2,500 runs planned for 2014 for 438 Shadow with these 5 operators

- Furthest Plug Set
  - MD 18,419’
  - Horizontal Length 8,038’
  - Planning 4.500” 11.60# field trials in 3-mile long lateral in Rockies

- Currently on 2 wells in the Utica area with 2 different customers
Future Portfolio

- **Current Offering**
  - 5.5” 20.00 – 23.00 #/ft casing – 10,000 psi at 350F

- **Projects Started***
  - 4.5” 11.60 – 13.50 #/ft casing – 10,000 psi at 350F – Ready Q2-14
  - 4.5” 15.10 – 16.60 #/ft casing – 10,000 psi at 350F – Ready Q2-14
  - 5.5” 23.00 – 26.00 #/ft casing – 10,000 psi at 350F – Ready Q3-14

- **Projects Upcoming***
  - 5.50” 17.00 – 20.00 #/ft casing – 10,000 psi at 350F
  - 5.00” 21.40 – 23.20 #/ft casing – 10,000 psi at 350F
  - 5.50” 20.00 #/ft casing – 15,000 psi at 450F
  - 5.00” 18.00 – 20.30 #/ft casing – 10,000 psi at 350F

*All projects subject to change based on market demands
Ball-Activated Completions
Increase Efficiency and Performance In Long Laterals

- **NO THROUGH-TUBING INTERVENTION**
  - Reduce risk by eliminating through-tubing wireline or coiled-tubing trip to fracture the well

- **SIMPLIFIED LOGISTICS**
  - Pressure pumping is the only service required on location

- **CONTINUOUS FRACTURING**
  - Eliminate down time between stages for non-stop fracturing
  - Reduce cycle time from weeks to days

- **NO POST-FRAC MILLING REQUIRED**
  - Produce through ball seats and eliminate post-frac milling requirements

**FRACPOINT™ MAXIMIZES EFFICIENCY AND PERFORMANCE**
Coiled Tubing-Activated Completions
Design An Aggressive Frac While Reducing Risk

**OPTIMIZE PROPPANT DISTRIBUTION AND HEIGHT CONTAINMENT**
- Stimulate through a single point of entry to deliver optimal proppant and fluid placement to intended stages

**MONITOR DOWNHOLE PRESSURES IN REAL TIME**
- Identify early warning signs to take preventative measures against screenouts

**REDUCE IMPACT OF SCREENOUTS**
- Immediate clean-out with coiled tubing already down hole
- Reduce NPT and get back online faster

**MINIMIZE HORSEPOWER**
- Reduce hydraulic horsepower needs

**OPTIPORT™ INCREASES ACCURACY AND REDUCES RISK**
Integrated Completion and Frac Design Delivers Value

Maximum HHP Required

- Plug-and-Perf: 21,000
- OptiPort Stimulation Treatment: 6,700 (68% reduction)

EUR (MMCFE)

- Plug-and-Perf: 3,100
- OptiPort Stimulation Treatment: 6,500 (107% improvement)
IDEAL “Plug and Perf” Frac

Uniform Fracs / Zone stimulation

Equal Flow division and proppant placement:
20 bpm – 80k # ea

100 bpm – 400k # prop
ACTUAL “Plug and Perf” Frac

- Potential limited # of perfs frac’d
- Erratic proppant placement
- Potential break into non-desired zones!

Limited # of Perfs Stimulated

50k #  350k #

100 bpm – 400k # prop

Path of least resistance

Waste
OptiPort™
Case Histories

- **2nd job in Granite Wash** – 30 stages – 18,300 ft MD / 12,000 ft TVD
  - Stimulation results

### Table 1. Stimulation job results – Comparative Summary Table

<table>
<thead>
<tr>
<th>Parameter / Well:</th>
<th>A (Plug and Perf)</th>
<th>B (Targeted)</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Frac Stages:</td>
<td>10 (with 3 clusters per stage)</td>
<td>30</td>
<td>None</td>
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<tr>
<td>Frac Spacing (ft):</td>
<td>165</td>
<td>164</td>
<td>None</td>
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<tr>
<td>Fluids Type:</td>
<td>HCI Spearhead, Slickwater fluid</td>
<td>HCI Spearhead, Slickwater fluid</td>
<td>None</td>
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<tr>
<td>Proppant Type:</td>
<td>100 mesh sand, 40/70 Ottawa white and Resin Coated with 2% resin coating</td>
<td>100 mesh sand, 40/70 Ottawa white and Resin Coated with 2% resin coating</td>
<td>None</td>
</tr>
<tr>
<td>Total Clean Fluid Pumped (gal):</td>
<td>9,344,170</td>
<td>9,568,993</td>
<td>+2.4%</td>
</tr>
<tr>
<td>Total Proppant Placed (lbs):</td>
<td>3,675,280</td>
<td>3,772,380</td>
<td>+2.6%</td>
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<tr>
<td>Average Frac rate (bpm):</td>
<td>99</td>
<td>40</td>
<td>-60%</td>
</tr>
<tr>
<td>Average Treating Pressure range (psig):</td>
<td>5,852 to 6,801</td>
<td>4,125 to 6,935</td>
<td>-30% to +2%</td>
</tr>
<tr>
<td>Average HHP range:</td>
<td>13,889 to 16,387</td>
<td>3,004 to 5,517</td>
<td>-78% to -66%</td>
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<tr>
<td>Maximum HHP required:</td>
<td>20,630</td>
<td>6,693</td>
<td>-68%</td>
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</table>

SPE 163820
What to do?

Begin with the Hydraulic Fracturing in Mind!
Treatment Design Sample

- 17 propped fracture stages
- 2 Acid stages
- 3 Propped fracture designs (Alpha, Beta, Gamma)
- 80’ cluster spacing = 63 perforated intervals
# Treatment Designs

<table>
<thead>
<tr>
<th>DESIGN</th>
<th>ALPHA</th>
<th>BETA</th>
<th>GAMMA</th>
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<tbody>
<tr>
<td>Fluid</td>
<td>X-linked</td>
<td>Tailored</td>
<td>Slick</td>
</tr>
<tr>
<td>Gal/lb</td>
<td>0.7</td>
<td>1.09</td>
<td>1.66</td>
</tr>
<tr>
<td>Mlb/ Cluster</td>
<td>70</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Bbl/cluster/min</td>
<td>18</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Max conc., psa</td>
<td>6</td>
<td>2.5</td>
<td>1.5</td>
</tr>
<tr>
<td>% Pad *</td>
<td>38</td>
<td>29</td>
<td>58</td>
</tr>
<tr>
<td>70/140 mesh</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Sweeps</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Proppant 1</td>
<td>40/80 HydroProp</td>
<td>40/80 HydroProp</td>
<td>40/70 Sand</td>
</tr>
<tr>
<td>Proppant 2</td>
<td>30/50 EconoProp</td>
<td>30/50 EconoProp</td>
<td>40/80 HydroProp</td>
</tr>
<tr>
<td>Proppant 3</td>
<td>20/40 EconoProp</td>
<td>----</td>
<td>30/50 EconoProp</td>
</tr>
</tbody>
</table>
We Know Everything about Fracs except,

The fracture half-length,

The fracture height,

The fracture orientation,

And

The fracture location once it leaves the wellbore
Down-hole Shale Well Monitoring Results

Dots show all events that were detected. Beach balls show focal mechanism calculated from downhole array.
How do you simulate this?

- With GOHFER/MShale
Magnitude: Integrated Science

Borehole & Surface Microseismic Monitoring
Introduction

Applications

- **Real-time Engineering & Monitoring**
  - Fracture dimensions
  - Screen outs
  - Geohazard avoidance
  - Thief zones
- **Post-Job Analysis**
  - Characterizes far field response
  - Fracture model calibration
  - Reservoir/Geomechanical model calibration

Compared to the Frac job

- Energy represented by microseismic events is infinitesimal
- Volume represented by microseismic event displacements is very small
Microseismic Data

- Displacements on weak planes (primarily shear)
- Some reservoirs have limited (no) locatable events
- May/may not represent stimulated rock SRV???
- Variations across play and stages
- Can we connect the dots?
SRV or Microseismic Volume?

- Began as drawing a rectilinear volume around the events to algorithms based on magnitude of events.
- Still it’s only a visual concept.
- Production depends on:
  - Frac surface area
  - Connectivity
  - Conductivity
Basic Microseismic Display
Pitfalls of “Dots in a Box”
Events Original vs “Cleaned”

Original Data

“Cleaned” Data
Interactive elapse time analysis couples stimulation model, pumping and MS data

Other elapse time parameters can be easily evaluated/highlighted/removed
- Magnitude vs. Proppant loading, Rate or Pressure
- Event Count vs. Rate (Q) or $\Delta Q/\Delta T$
- Other geometric parameters

Requires a processes to evaluate overlap with previous stages during pumping
- Cumulative “μSRV” type calculation

Next Step-Production Modeling
Options for the Future (now) with Less or No Water

- **Water Treatment**
  - H2prO™

- **Fluids that use produced Water or Sea Water**
  - Lightning
  - SPECTRAFRAC®
  - ShaleXcel™
  - PRISMFRAC PLUS™

- **Fluids that can be recycled**
  - AQUASTAR®

- **Fluids that use less water or no water**
  - FOAMED AQUASTAR®
  - VAPORFRAC®
  - POLY CO₂ FRAC SYSTEM
  - SUPER RHEOGEL®
  - METHOFRAC®
  - SUPER CO₂ FOAM®
Oilfield Water Management

Transforming a waste product into a resource
# Produced Water Frac System Advisor

## TDS vs. Total Hardness

<table>
<thead>
<tr>
<th>TDS</th>
<th>Total Hardness</th>
<th>100°F</th>
<th>130°F</th>
<th>150°F</th>
<th>170°F</th>
<th>200°F</th>
<th>250°F</th>
<th>300°F</th>
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</thead>
<tbody>
<tr>
<td>300,000</td>
<td>80,000</td>
<td>A</td>
<td>B</td>
<td>E*</td>
<td>E*</td>
<td>E*</td>
<td>E*</td>
<td>E*</td>
</tr>
<tr>
<td>200,000</td>
<td>25,000</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>E*</td>
<td>E*</td>
<td>E*</td>
<td>E*</td>
</tr>
<tr>
<td>150,000</td>
<td>12,000</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>E*</td>
<td>E*</td>
</tr>
<tr>
<td>100,000</td>
<td>7,000</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E*</td>
</tr>
<tr>
<td>50,000</td>
<td>4,000</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>E*</td>
</tr>
<tr>
<td>5,000</td>
<td>600</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>

### Fluid System Polymer Crosslinker pH Buffer Additional Items

<table>
<thead>
<tr>
<th>Fluid System</th>
<th>Polymer</th>
<th>Crosslinker</th>
<th>pH Buffer</th>
<th>Additional Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>GW-4LF</td>
<td>XLW-30AG and/or XLW-4L</td>
<td>BF-8L</td>
<td>Water filtered to 25 microns</td>
</tr>
<tr>
<td>B</td>
<td>GW-4LF</td>
<td>XLW-30AG or XLW-24</td>
<td>BF-8L</td>
<td>Water treated and filtered to 25 microns</td>
</tr>
<tr>
<td>C</td>
<td>GW-3LDF</td>
<td>XLW-30AG</td>
<td>25% Caustic</td>
<td>Water treated and filtered to 25 microns</td>
</tr>
<tr>
<td>D</td>
<td>GW-3LDF</td>
<td>XLW-30AG</td>
<td>25% Caustic</td>
<td>Water treated and filtered to 25 microns</td>
</tr>
<tr>
<td>E*</td>
<td>GLF-3B</td>
<td>XLW-60</td>
<td>25% Caustic or BF-10L</td>
<td>Water treated and filtered to 25 microns</td>
</tr>
</tbody>
</table>

Custom formulations available for high TDS waters at elevated temperatures
FRP-1 Friction Reducer for High TDS Produced Water

■ Technology Overview

- Almost half of fracturing treatments are slick water
- High salinity (both TDS and hardness) detrimental to the polymer hydration
- Conventional friction reducers not able to provide fast friction reduction often achieved in fresh water
- New friction reducer chemistry compatible with high TDS and high hardness water

■ Technology Benefits

- Reduce the fresh water volume needed
- Eliminate cost associated with water disposal
- Reduce environmental footprint
- Effective friction reduction achieved
- Cost effective and operational friendly
FRs Performance Comparison in Produced Water with 200k TDS and 40k Total Hardness

- **1 gpt FRP-1**
- **1 gpt Conventional FR 1**
- **1 gpt Conventional FR 2**
Stages 14-17 Actual Pumping Results in 240k TDS and 50k Total Hardness Water at Hobbs, NM

1.5 gpt FRP-1 at 57 bpm STP=5770
1.5 gpt FRP-1 at 60 bpm STP=5270
1.0 gpt FRP-1 at 60 bpm STP=5880
2.0 gpt Conventional FR at 47 bpm STP=7000 psi

FRP-1 Performance vs Conventional FR

Elapsed Time (min)

FRP-1 (gpt)
STP (psi)
Cln Rate (bpm)
AquaPerm™

- Friction reducer in slick water fracs
- Linear guar replacement
- Can be used in hybrid fracs to replace FR in slick water frac portion and linear guar.

<table>
<thead>
<tr>
<th>Well Number</th>
<th>9 Mo Cum Prod (BOE) / Tot Prop (lbs) / Lat (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>w/o Product A</td>
</tr>
<tr>
<td>2</td>
<td>w/o Product A</td>
</tr>
<tr>
<td>3</td>
<td>w/o Product A</td>
</tr>
<tr>
<td>4</td>
<td>w/o Product A</td>
</tr>
<tr>
<td>5</td>
<td>with Product A</td>
</tr>
<tr>
<td>6</td>
<td>with Product A</td>
</tr>
<tr>
<td>7</td>
<td>with Product A</td>
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<tr>
<td>8</td>
<td>with Product A</td>
</tr>
<tr>
<td>9</td>
<td>with Product A</td>
</tr>
<tr>
<td>10</td>
<td>with Product A</td>
</tr>
</tbody>
</table>
AquaPerm™

- 7 treated wells
- 4 offset wells
- Eagle Ford Shale formation in South Texas
- 200nD to 600 nD permeabilities
- 20 ppt linear gel was replaced with 4 gpt Maxperm20A
- Horizontal wells
- Each treated well showed production improvements of 30% to 70% vs the offset wells.
X-linked Frac Fluid for Produced Water

**Technology Overview**

- Guar derivative crosslinked with metal crosslinker
- Specifically designed for produced water with extreme high salinity
- Simple system to minimize reformulation required for water quality variations observed in produced water from various regions
- Cost competitive to conventional frac fluids

**Technology Benefits**

- Applicable for most of the produced water
  - Up to 300K ppm TDS
  - More than 50K ppm total hardness
- Stable fluid for high temperatures
  - 275 F to 300 F for high TDS and high hardness water
- No special requirements in operation
- Baker Hughes patent being filed
USA Leads the World?

- Normally, the USA Leads the Fracturing World
  - All new technologies and techniques are tried in the US first, and then spread to the Rest of the World
- The One Exception to This is Environmental Compliance
  - The USA is following Europe

Global Fracturing Activity

- USA 75%
- Canada 10%
- Rest of the World 15%
Baker Hughes – Environmental Stewardship

Chemical Improvement
- CEPR
- SmartCare™
- Products and Systems

Equipment Innovations & Water Management

Environmental Services Support & Regulatory Reporting Support
Environmental Services Facilities

U.S.A.

ESG - Norway
**OCNS or OSPAR**

Locations where OCNS classifications or OSPAR data are currently being requested

- **OSPAR** = Oslo/Paris Convention
- **OCNS** = Offshore Chemical Notification System (UK)
SmartCare™ Family of Solutions

- Certified based on the following criteria:
  - CEPR* assessment
  - Performance
  - Value
  - Compatibility

- Wide range of additives and systems for:
  - Cementing
  - Drilling fluids
  - Stimulation fluids
  - Upstream chemicals

* - Corporate Environmental Protection Rating
SmartCare™ Designed To Have

- **Credibility** in terms of the criteria and rationale used for the ranking
- **Transparency** for easy explanation to stakeholders such as customers or regulators
- **Scientific Soundness**, with a documented basis for criteria and ranking of each hazard
- **Validity**, based as much as possible on existing systems and criteria
- **Practicality**, considering the range of chemicals used in well service products, the profile of the suppliers and the data normally available for these chemicals
- **Quantitative** to indicate relative “green-ness”
# SmartCare™ Example Hazard Assessment

<table>
<thead>
<tr>
<th>Component</th>
<th>Methanol 67-56-1</th>
<th>Component A CAS# A</th>
<th>Component B CAS# B</th>
<th>Water 7732-18-5</th>
<th>Total Score</th>
<th>Weight Score</th>
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</thead>
<tbody>
<tr>
<td>CAS Number %</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>Environmental Criteria</td>
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<td>Acute Aquatic Toxicity</td>
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<td>Priority Water Pollutants</td>
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<td>1</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td><strong>Total score/component</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>4.4</td>
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<td>Toxicological Criteria</td>
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<td>0</td>
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<td></td>
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<td>Reproductive and Developmental</td>
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<td>0</td>
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<td>Corrosive/Irritant</td>
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<td>1</td>
<td>1</td>
<td>0</td>
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</tr>
<tr>
<td><strong>Total score/component</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>223</td>
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<tr>
<td>Physical Hazards %</td>
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<tr>
<td>Explosive</td>
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<td>Oxidizer</td>
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<tr>
<td>Corrosive</td>
<td>0</td>
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</tr>
<tr>
<td><strong>Total score</strong></td>
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<td>100</td>
<td>2.5</td>
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</table>

**Product Score**

(Environmental, Toxicological and Physical Hazard Criteria)

Data gap = 1

From SPE 147534
SmartCare™ Hazard Assessment

- In a World Where Every Country, State and/or Region has Differing Environmental Compliance Standards, the SmartCare™ Process Provides the Following Company-Wide Benefits
  - Global assessment of environmental performance
  - Criteria for continuous improvement
  - Comparison of products with similar functionality
  - Transparency and auditability
  - Starting point for the introduction of new products into specific areas and/or markets
  - Removal of products based on high Hazard Assessment score
Water Management in Shales

- Most **Shale** wells produce **Very little** or **No water** (Exception – Antrim, a Biogenic Shale)

- **However:**
  - Water may be produced later in well life **or** from fracturing into Water Zones
  - With anticipated high numbers of shale wells, a small amount of water per well can add up to **large volumes**

- **Water Problems** are primarily associated with **Frac Flowback Water** (part of Complete Water Cycle)

- “**Managing the Complete Water Cycle**”
H2prO Water Management Service Treatment Solutions
Baker Hughes

SR

HMS

HD

DST
Summary

- Which fluid/completion/design? Which reservoir!?
- Microseismic is part of the solution but needs a combination of all other parameters
- Fracturing fluids are available to use any quality water including produced waters or sea water
- BHI has the necessary technology, expertise and personnel to reduce risk, begin with the refrac in mind.
- An integrated multi-disciplinary is key