Executive Overview

- Fracture Fluids 101
- Understanding Reservoir Properties
  - Permeability
  - Porosity
  - Fracture Geometry
- Fluids Behavior
FTS International is a leading independent provider of oil & natural gas stimulation services with expertise in high-pressure hydraulic fracturing.
Reservoir Properties

• Porosity
  – Volume of All Pore Spaces in a Formation

• Permeability

• Degree of Connectivity Between Pore Spaces in a Formation
  • ↑ Perm Need Shorter Fracs
  • ↓ Perm Need Longer Fracs
    – Less Conductive
    – Notoriously Low Perm in Shale

• Conventional By Wing Fracture System Versus Complex Fracture Systems
Porosity & Permeability

Porosity
Spaces between the material

Permeability
Connectivity of pore spaces
## Completion Fluids

<table>
<thead>
<tr>
<th></th>
<th>Slickwater</th>
<th>Linear</th>
<th>Crosslinked</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Viscosity</strong></td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td><strong>Pump Rate</strong></td>
<td>High</td>
<td>Moderate / High</td>
<td>Low / Moderate</td>
</tr>
<tr>
<td><strong>Proppant Transport</strong></td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td><strong>Proppant Concentration</strong></td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td><strong>Water Volume</strong></td>
<td>High</td>
<td>Average</td>
<td>Low</td>
</tr>
</tbody>
</table>
Fluid Geometry

Slickwater

Linear

Crosslinked
Slickwater Fracture Treatments

- Friction reducers are composed of ultra high molecular polyacrylamide polymers
- Sold as liquid invert (oil external) emulsion
- Very little viscosity contribution in mix water
- Three phases of flow
  - Laminar Flow – Friction Reducer No Benefit
  - Turbulent Flow – High Friction Pressure
  - Transition Zone – Eddies and Microvortices
- Elastic polymers dampen or suppress energy of eddies
- Pushes Laminar behavior to higher rates
- High hardness and Chlorides affect the performance of the Friction Reducer
Guar-Based Viscosifiers

- Gels used by FTS are based on guar gum or anionic guar (CMHPG)
- Advantage of guar gum
  - Readily available (84,000 metric tons of powder produced annually)
  - Cold water soluble (~80% hydration in 3 min)
  - Tolerates most water quality
  - Effective viscosifier at low concentrations (0.12% to 0.48%)
  - Good friction reduction
  - Good fluid loss control (forms filter cake)
  - High viscosity gel (easily crosslinked)
  - Easily degraded for clean up (acid, enzymes, oxidants)
  - Dispersible in oil (slurry is designed for easy metering and dispersion)
  - Substantial progress in efficiency made over time
    - In 1978, 40 ppt base gel viscosity in 3 min was 32 cP
    - In 2010, 40 ppt base gel viscosity in 3 min was 45 cP
Energy Solutions Worldwide:

80% of all guar grown in western India

Pods
Seeds
Splits
HVG-01 Powder
Guar Hydration Process

Guar Particles
< 200 mesh

Swollen Guar Particles

Early Time
H₂O
Mixing Energy
Has no Effect
On Swelling

Later Time in Hydration

After swelling, mixing energy assists washing polymer strands off particle
Acid Fracturing

Process to increase production of a formation by pumping a blend of acid under pressure to extend a fracture. Through reaction, the acid dissolves or etches the fracture walls and creates wormholes within the formation.
Matrix Acidizing

Creates a region of enlarged pore spaces and/or wormholes around the wellbore and removes drilling mud damage to wellbore area
Sandstone Acidizing – The Six Step Process

1. Determine the presence of acid removable skin damage
2. Determine appropriate fluids, acid types, concentrations, and treatment volumes
3. Determine the proper treatment additive program
4. Determine treatment placement method
5. Ensure proper treatment execution and quality control
6. Evaluate the treatment

Gelled Acid Overview

• Gelled acid is created from adding a gelling agent to hydrochloric acid
• Gelling the acid creates a high viscosity acid gel that is used for:
  – Reducing friction pressure along the pipe while moving fluid
  – Allowing for deeper penetration of the acid system before it is spent
  – Reducing damage from fines created by the reaction of HCL and the formation by keeping fines in suspension for later flowback
• **Components:**
  – AG-1: Acid Gelling Agent (Anionic)
  – AG-2: Acid Gelling Agent (Cationic)
  – Corrosion Inhibitor – Verify corrosion inhibitor before choosing the gelling agent!
Mud Acid Overview & Mixing

- Mud Dissolving Acid is used to widen the pore throats and pore spaces in order to increase permeability around the wellbore, and also to remove damage
- Blend of Surfactants, inhibitors, HCL and HF
- Damage Mechanisms:
  - Drilling Fluids
  - Clay Swelling / Migration
  - Formation Destabilization
  - Fluid Incompatibilities

- Typically mixed at a 12% HCL 3% HF ratio. HF is used to dissolve quartz

<table>
<thead>
<tr>
<th>HCl/HF Acid Mixture</th>
<th>Starting HCl %</th>
<th>Ammonium Bifluoride (lbs/1000 gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6% HCl / 1.5%</td>
<td>7.50%</td>
<td>208.5</td>
</tr>
<tr>
<td>12% HCl / 3%</td>
<td>15%</td>
<td>417</td>
</tr>
<tr>
<td>14% HCl / 6%</td>
<td>20%</td>
<td>834</td>
</tr>
<tr>
<td>25% HCl / 3%</td>
<td>28%</td>
<td>417</td>
</tr>
</tbody>
</table>
Emulsified Acid Overview

- The Venus Acid System is an oil external acid emulsion system that allows deeper penetration of live acid by slowing down the acid reaction rate.
- Thus allowing for a delayed reaction and greater rock contact away from the wellbore.
- For use with Hydrochloric Acid.
- The Hydrochloric Acid is emulsified in a refined oil by using an oil external emulsion surfactant.
Venus Acid Overview

Fluid Requirements
1. Oil-Acid
2. Emulsifier
3. Good Agitation

Oil

= acid droplet
Self Diverting Acid Fluid System Overview

- The Mars Acid System is a gelled acid system that overcomes some of the traditional problems encountered when trying to increase the viscosity of acid stimulation treatments.
  - Features & Benefits
    - Fluid system is designed to thicken after significant acid spending, pH > than 2
    - Early fluid viscosity provides some retardation for near well-bore area to allow deeper placement
    - (SDA System) Initial spending of live acid during etching and worm-holing produces a pH increase thus initiating cross-linking of the polymer and causing subsequent diversion
    - Reduced Frictional Pressures
    - Cost-effective
    - Viscosity declines after acid completely spent, but maintains enough viscosity to aid in recovering insoluble fines during flow back process