Fracturing Challenges
The Journey to Innovative Solutions

Mohammed Bataweel
Production Technology Team
EXPEC Advanced Research Center

December 13, 2014
Outline

• Introduction
• Fracturing process
• Challenges
• R&D in fracturing
  ▪ Fracture Mechanisms
  ▪ Fracturing Fluids
  ▪ Waterless Fracturing
Hydraulic Fracturing

Process that involve injecting fluids at high pressures till the failure point of the rock to initiate and propagate cracks in the direction of the maximum stress.
Fracturing Process

- Inject fracturing fluids to apply tensile stress to that exceed the cracking pressure of the rock.
- Prop the fracture open using sand or ceramics
Stress Orientation and Rock Strength

\( \sigma_{\text{Min}} \)

\( \sigma_{\text{Max}} \)
Challenges

- High Completion and Operational Cost at Multistage Fracturing in Horizontal Wells
- Technical Challenges
  - Fracture Tortuosity
  - Extensive Leak-off
  - Damage in Fracture Conductivity
- Water Requirements
  - Quantities
  - Quality
Fracturing Horizontal Wells

- **Mechanical isolation is required**
  - Openhole packers or sand plugs
  - Costly and time consuming
Fracture Tortuosity

**Aligned fracture**

**Tortuous fracture**

Fracture Tortuosity
- High friction near wellbore
- Impact proppant placement
Extensive Leak-off

Effect of high leak-off

- Affect the fracture dimensions
- Formation damage
- Proppant placement
Fracture Conductivity

Zone-2
- Clay
- Incompatibility
- Water blockage

Zone-3
- Precipitation
- Gel residues
- Proppant crushing & embedment

---

Saudi Aramco: Public
Challenges in the Region

- Shortage of fresh water resources
- Lack of infrastructure to support commoditizing fracturing activities
Evolution of Fracturing Technology

- Vertical with single fracture
- Multistage fracturing of horizontal wells cased hole
- Multistage fracturing of horizontal wells openhole completion system
- Multistage fracturing of horizontal wells openhole
Fracture Orientation in Horizontal Wells

Orientation of Fractures

- Transverse Fracture
- Re-oriented Fracture
- Longitudinal Fracture

![Diagram illustrating different types of fractures in horizontal wells.](image)
Fracture Mechanisms R&D

Objective

- Develop cost effective technologies by eliminating mechanical isolation in horizontal open-hole fracturing.
- Create multiple hydraulic fractures along a horizontal open hole.
- Understanding the controlling parameters and near wellbore stress of fracture initiation.
- Develop oriented notching tools.
Fracture Mechanisms R&D

- Oriented Fracturing (Vertical Mini-hole)
- Openhole Fracturing (Radial Notch)
Fracturing Mechanics – Oriented Fracturing

Concept

✓ Creating a vertical minihole (2 inches in diameter & 2 ft height) via jetting from any point along a horizontal well.

✓ This vertical hole goes beyond the near wellbore stress field; therefore,

✓ the fracture will initiate from this hole as it is designed to have the lowest breakdown pressure.

✓ A jetting tool was manufactured and yard tested on large scale cement block.

What is the optimum hole, orientation? Diameter? Length?
Mini-Hole Orientation
Hole Diameter

Q = 30 bbls/min, \( \rho = 10 \text{ lb/gal} \), \( N = 1 \), \( D_p = 2'' \), and \( C_d = 0.8 \),
Hole Length

Near Wellbore Stresses (psi) vs. (r/rw)

- Elastic-Radial Stress (psi)
- Elastic-Tangential Stress (psi)
- Plastic-Radial Stress (psi)
- Plastic-Tangential Stress (psi)

Key:
- $\sigma_r$
- $\sigma_\theta$
- $P_w$
Block Testes conducted @ 6”x6”x10”.

Lab testing prove the ability of this technique to place and initiate the fracture at created Mini-hole.

Yard testing of oriented jetting tool is capable to create the required jetting dimension.
Fracturing Mechanics — Openhole Fracturing

Concept:

✓ Creating weak points along horizontal wells based on reservoir properties
✓ Simultaneously initiating fractures at all week points
✓ Fluid diversion to stop dominant fractures to sequentially propagate all fractures
✓ Degradable diverting material to cleanup all fractures

Wellbore preparation:
- Seal natural fractures
- Notching

Fracture Diversion to allow propagation of minor fractures

Alternate diverting/fracturing fluids

Multiple fractures created without mechanical isolation
Fracturing Mechanics — Openhole Fracturing

Experimental

- Acoustic sensors
  - Location of sound
  - Fracture orientation
  - Fracture geometry

Field Trail

- Preliminary results indicated multiple fractures
- Improved productivity compared to adjacent wells in the field
Fracturing R&D

Fracture Mechanisms
- Horizontal Openhole Fracturing
- Oriented Fracturing

Fracturing Fluids
- Seawater Fracturing Fluids
- Exothermic Reaction
  - Polymer Based
    - Viscoelastic Surfactant with Nano-particles

Advanced Techniques
- Laser
- Plasma
Objective

- Develop superior fracturing fluid using sea waters in the Kingdom.
- Alleviate burden of lacking fresh water resources
- Enhanced fracture cleanup and conductivity
- Simplified chemistry for easy QA/QC on location
- Applicable to both conventional reservoirs and unconventional resources
- Applicable to temperature up to 350°F
Requirements of Fracturing Fluid

- Provide good proppant transport property
- Compatible with the formation rock and fluids
- High fluid efficiency - low fluid loss
- Low friction during pumping
- Build viscosity inside the fracture
- Break down effectively after treatment - low residue
Fracturing Fluid Composition

- Water
- Gelling agent
- Cross-linker
- Gel Breaker
- Clay stabilizer
- Friction reducer
- Biocide
Technical Challenges by HT & Seawater

- **Rheology**
  - **Hydration**
    - Less hydration in high salinity and hardness
  - **Crosslinking**
    - Impact pH by precipitating hydroxides
  - **Stability**
    - Available systems shows low thermal stability at 350° F

- **Cleanup**
  - Potential scales forms in the fracture
  - High reactivity of breakers at high temperatures
  - Inefficient removal of polymer from the proppant pack in the fracture

- **Scaling**
  - Incompatibility with pH modifiers (hydroxides)
  - Incompatibility between filtrate and formation brine (sulfates)
High Temperature Seawater Fracturing Fluids R&D

Polymer Based

Surfactant Based
Comparison Between Polymer & Surfactant Based Fracture Fluids

<table>
<thead>
<tr>
<th>Property</th>
<th>Polymer</th>
<th>Viscoelastic Surfactant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Stability</td>
<td>More stable</td>
<td>Less stable</td>
</tr>
<tr>
<td>Fluid Efficiency</td>
<td>More efficient</td>
<td>Need Leak-off control</td>
</tr>
<tr>
<td>Mixing</td>
<td>Several Steps</td>
<td>Easier</td>
</tr>
<tr>
<td>Cleanup &amp; Fracture Conductivity</td>
<td>Residue</td>
<td>Cleaner &amp; better conductivity</td>
</tr>
<tr>
<td>Cost</td>
<td>Cheap</td>
<td>Expensive</td>
</tr>
</tbody>
</table>
Seawater Fracturing Fluid

Polymer
M.W. 200K to 2 Million

crosslinker

Viscoelastic Surfactant
M.W. Hundreds

Entangled Worm-like Micelles

Broken Polymer Gel
Insoluble residue

Broken VES Gel Soluble spherical micelles
Seawater Frac Fluid - Viscoelastic Surfactant Concept

✔ Use viscoelastic surfactant as gelling agent

✔ New mechanism to associate into elongated micelles:
  ✔ Based on use of selected nanoparticles
  ✔ Nanoparticles are able to ‘pseudo-crosslink’ elongated micelles into 3-D structures

Nettesheim et al. Langmuir 2008, 24,
Seawater Fracturing Fluid — Polymer-based

Concept

✓ Improve current polymers thermal stability or design new copolymer

✓ Develop new sulfate scale inhibitor that operates at 350°F without interfering with crosslinking process
Effect of Seawater on high temperature fracturing fluid

Viscosity (cp) @ 40 S-1

Elapsed time (min)

Temp. @ 350°F

Seawater

Fresh water
Effect of high temperature on seawater fracturing fluid
Exothermic Reaction R&D

Objective

• Generate multiple fractures
• Minimize water requirement during fracturing
• Improve wellbore cleanout

Concept

✓ Incorporate exothermic reactants with the fracturing fluid to generate in-situ pressure and heat pulses.
Exothermic Reaction R&D

Chemical → Pressure + Heat
Fracturing R&D

Fracture Mechanisms
- Horizontal Openhole Fracturing
- Oriented Fracturing

Fracturing Fluids
- Seawater Fracturing Fluids
- Polymer Based
- Surfactant Based
- Exothermic Reaction

Waterless
- Laser
- Plasma
Waterless Fracturing Techniques R&D

Objective
• Develop waterless fracturing technology.
• Non-damaging
• Cost effective
• Environmentally friendly

Concept
• Generate reservoir stimulated volume
• Utilize Laser to enable current fracturing techniques
• Create multi lateral, multi perforated tunnel, slots and notches with geometry control
• Generate Laser at surface and transmitted via fiber optics
Laser Fracturing
Plasma Fracturing

Concept

☑ Energy storage & pulse release (pulsed power technology concept)

☑ Discharging in nanosecond window to create high current electrical pulse carrying power in giga-watt range

☑ High-power electrical discharges transformed into fast expanding plasma in water-filled borehole
Plasma Fracturing
Conclusion
Thank You