Practical Issues Related to sc-CO$_2$
Well Construction for CO$_2$
Sequestration Projects

Brookhaven National Lab
Supercritical Carbon Dioxide &
Materials Interaction
Overview

Cement Systems & Cementing
- Chemical Durability of cements
- Mechanical durability of cements
- Mud Displacement Factors
- Cement Placement & Reverse Circulation
- Case History

Casing and Well Design
- Casing Design
  - Connections
  - Metallurgy
- Well design Optimization
- Identify chemistry of injection fluid
Chemical Durability of Cement

Temperature Related
- Previously 30 - 40% additional crystalline silica was thought enough to provide strength stability
- New published data up to 600 °F shows a need of up to 70% Silica added for strength stability

Chemical Attack
- Chemical attack
  - CO2
  - H2S
- Need resistance to chemical attack
  - Latex Cements
  - Fly Ash / Calcium Aluminate cement blend
    (Developed by Sugama of BNL)
Mechanical Durability

Cyclic Stress Loading

• Pressure induced
  – Injection
  – Stimulation
  – Swapping out fluids of different density

• Temperature Induced
  – Drilling
  – Production
  – Injection

Cement Failure
Conventional Cement - 2D Modeling

Thermal Stress, $\Delta T = 200^\circ C (360^\circ F)$

Tensile Failure Occurs!!
Ductile Cement - 2D Modeling

During heating plastic strains develop but NO cracking or de-bonding occurs.

Thermal Stress, $\Delta T = 200^\circ C (360^\circ F)$
Cement Durability

Conventional Cement  Ductile Cement
Mud Channeling

- Allow contact of casing with well fluids - CO2 & Water
- Allow Interzonal Communication
  - Lost Production
  - Unwanted Production
  - Corroded Casing
Displacement Factors

- Mud Conditioning
- Mechanical Aids
  - Pipe Movement
  - High Port Up-Jet Float Shoe
- Centralization
- Fluid Velocity
- Spacers & Flushes
Definition of Standoff and Displacement Efficiency

Standoff = \( \frac{C}{A-B} \)

Displacement Efficiency = Cemented Area / Annular Area
Mud Conditioning

- LOW MOBILITY MUD
- MOBILE MUD
- FILTRATE
- FILTER CAKE
- CEMENT
- CASING
- FORMATION
Pipe Movement

- Removes Gelled Mud
- Rotation or Reciprocation
Centralization

• Centralization critical for complete mud displacement
# Centralization

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<th>Standoff</th>
<th>Displacement</th>
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Affect of Flow Rate

Plug Flow  Laminar Flow  Turbulent Flow
## Velocity

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<th>Rate (bpm)</th>
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Spacers and Flushes

- Fluid Compatibility
- Fluid Separation
- Aid in Mud Displacement
- Formation Protection
- Solids Suspension
Cement Placement

Reverse Circulation Cementing
Reverse Circulation

Key Advantages

- Reduced hydraulic horsepower
- Reduce ECD’s
- Shorter cement thickening times
- Reduced cost for retarder
- Quicker strength development
- Improved safety and environmental management

Conventional vs. Reverse
Lower ECD - Reverse Circulation

**Conventional Circulation**

Conventional Circulating Pressure and Density at Fracture Zone.

- Circulating Pressure
- Hydrostatic Pressure

**Reverse Circulation**

Reverse Circulating Pressure and Density at Fracture Zone.

- Circulating Pressure
- Hydrostatic Pressure

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Key Advantages

Reduced ECD

• Conventional circulation involves lifting heavy cement in a small annulus

• Reverse Circulation involves lifting drilling fluid through nearly entire job with little flow restriction of mud in casing
**Key Advantages**

**Short TTT/Reduced Cost**
- Conventional circulation
  - 100% of cement exposed to BHCT
  - Added time to displace
- Reverse Circulation
  - Only lead portion exposed to BHCT
  - Retarder can be staged / reduced during job
  - No Displacement time
- Faster Set Time
Operational Challenges

- Determining Cement Location
- Rig-up
- Job Design and Execution
- Float Equipment
Case Histories

• 26 Jobs have been done in the West Coast Region since 2002
  – All geothermal except 3 jobs
  – Majority were volumetric w/ gamma ray tool and radio active tracer

• Locations
  – CA
  – Hawaii
  – Nevada

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Case History

Well Details
- New Production well
- CO2 zone @ 1200 ft.
- Past history of casing failure at that depth
- Problem cementing 13-3/8 inch casing due to lost circulation

Solution
- Used Foam cement for improved mechanical properties
- Used CO2 resistant blend to protect from CO2 attack
- Placed with reverse circulation
Casing Design

- Metallurgy of casing must be considered for expected environment
- Each Casing String must be evaluated for each well
- Carbon steel, high alloy, titanium, etc.
Casing Connections

- High Stress occurs in connections during thermal cycling
- Premium connections preferred over buttress

- a - compression loading
- b - Tension loading
- c - Non deformed
Summary and Conclusions

• Drilling sc-CO2 wells involves additional design challenges above normal geothermal and/or storage wells
• Mechanical and chemical cement durability must be taken into consideration
• Modeling of stress on cement and casing recommended for all designs
• Cement must cover entired casing annulus

• Special cement systems must be used when exposed to CO2 in presence of water
• Casing corrosion must be considered and needed metallurgy used to prevent corrosion
• Factors affecting displacement efficiency must be considered to insure competent cement sheath placement
• Chemical and mechanical considerations for casing design
Questions??

Comments??