SACROC CO$_2$ Flood Project Challenges: Past, Present, and Future

Presented at Collaborative Symposium on CO$_2$ EOR between Universities in Texas and Norway
Rice University Houston: November, 19-21
SACROC is in the Kelly-Snyder Field, largest of a chain of Canyon Reef Fields making up the Pennsylvanian Aged Horseshoe Atoll.
SACROC Unit Information

- Field discovery 11/1948
- Productive area: 49,980 acres
- Formation: Canyon Reef
- OOIP: 2,800 MMSTBO
- Oil column thickness: up to 900 ft in Platform
- Average depth: 6800’
- Discovery pressure: 3100 psi
- Oil gravity: 39 API
- HC GOR:
  - Original: 1000 Scf/Stbo
  - CO2 Flood: 2600 Scf/Stbo
- Rich gas, 230 Bbls NGL/Mmscf HC gas
- Total CO2 Flood Gas GOR: 30,000 Scf/Stbo
- 10/2013 Production & Injection:
  - 31,600 BOPD
  - 18,900 BPD NGL
  - 980 MMSCFID CO2 (90% Recycled)
SACROC Unit Performance History

- **11/1948:** Field discovery
- **9/1954:** Center Line Water Injection begins
- **Late 1971:** Pattern waterflood begins
- **1/1972:** CO2 injection begins
- **3/1974:** Peak oil rate (215,000 Bopd)
- **1975:** 20-acre infill drilling, 40-acre 5-spot development
SACROOC 4-Pattern Area CO2 Flood Pilot

- Pilot conducted in south part of Unit ahead of the CO2 injection expansion into the south of the Unit
- Pilot made up of four ~160-acre inverted 9-spot patterns
- 2000 BOPD+ of definitive oil response
- EOR was 10% of OOIP after 30% HCPV CO2 injection
- However, oil influx from outside project area complicates analysis; IWR<1.0

Cumulative CO2 Injection Bubble Map through January, 1996

Water injection from 1973 to 1981
CO2-WAG injection from 1981 to 1986
Pennzenergy suspected that SACROC hadn’t been effectively CO2 flooded
- Other West Texas projects beginning CO2 injection in the 1980’s and 1990’s had exhibited significant CO2 Flood EOR Wedges
- SACROC’s CO2 injection had been conducted using high WAG ratios, sometimes below MMP

Three focused CO2 flood test areas were initiated:
- Norflood
  - Focused on low permeability Middle Canyon
- Southwest Bank
  - Focused CO2 injection in lower permeability reservoir
- Center Line
  - Focused 40-acre 5-spot pattern development
Initial KM CO2 Flood Redevelopment

• KM Purchased SACROC in 2000

• Expanded upon Pennzenergy’s successful Center Line CO2 flood project

• KM expanded its CO2 pipeline infrastructure in 2003 by installing the Centerline Pipeline to deliver another 300 MMSCFD to the SACROC area and beyond
## SACROCOO Flood Redevelopment Project Areas 1996-2008

<table>
<thead>
<tr>
<th>Year</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Center Line 1 &amp; 2 Expansions (CL1 &amp; CL2)</td>
</tr>
<tr>
<td>2001</td>
<td>Center Line 3 (CL3)</td>
</tr>
<tr>
<td>2002</td>
<td>Center Line 4 (CL4)</td>
</tr>
<tr>
<td>2002</td>
<td>Center Line 5 (CL5)</td>
</tr>
<tr>
<td>2003</td>
<td>Bull’s Eye (BE)</td>
</tr>
<tr>
<td>2004</td>
<td>Center Ring 1 (CR1)</td>
</tr>
<tr>
<td>2005</td>
<td>Center Ring 2 (CR2)</td>
</tr>
<tr>
<td>2007</td>
<td>Southwest Center Line 1 &amp; 2 (SWCL1 &amp; 2)</td>
</tr>
<tr>
<td>2008</td>
<td>Southwest Center Line 3 (SWCL3)</td>
</tr>
<tr>
<td>2008</td>
<td>Gilligan’s Island (GI)</td>
</tr>
<tr>
<td>2008</td>
<td>South Platform (SP)</td>
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Platform development was deferred until all of the Central Plain areas were completed.
Platform CO2 Flood Development

- SACROC Platform Area has the thickest pay in all of SACROC
  - OOIP: 951 MMSTBO
  - Area: 5700 acres, 145 patterns

- Complex, Highly Heterogeneous Reservoir
  - Some Dual, Triple injection well completions used to better distribute CO2 injection
SACROC Pay Zone Intervals

Intervals

Cisco
Green Zone
MCN3
Lower Middle Canyon

Moderate matrix permeability, unconnected fractures result in fast processing rates in some areas, porosity lenses not well connected.

Thick and continuous with good matrix permeability. Characterized by highly permeable features that short circuit sweep through matrix.

High permeability matrix, good continuity, excellent sweep.

Layered and continuous. Low porosity and matrix permeability. Few fractures or high permeability features.
Platform Area Green Zone

Navassa Island Modern Day Green Zone Analog

Karsted Core Sample
• Expanding CO2 Flood into the Platform meant confronting severe CO2 channeling issues
  – Several cases of CO2 breaking through within hours of starting CO2 injection

• IDEA (Infill Development Experimental Area)
  – 10-acre infill drilling & conversion project was implemented to create 20-acre 5-spot patterns
  – Objective was to increase recovery by connecting up discontinuous pay and allow faster processing of lower permeability layers

• Unfortunately the infill drilling also connected up the high permeability layers/channels
CO2 Channeling Issues

- Early CO2 channeling issues resulted in several patterns having to be shut-in
  - Cross-linked polyacrylate gel treatments successfully controlled many of the problems (except in the most extreme cases)
  - The long pump times required for placing the polymer treatments resulted in substantial production downtime
P2 Project Design Changes

• Pre-Injection Polymer Treatments were pumped
  – Pumping polymer before beginning CO2 injection avoided significant production downtime

• Where economically justified, three injection well completions were implemented to better distribute CO2 injection

• Horizontal producer was drilled on east side of project
  – Replaced drilling 5 vertical wells
### SACROC Pattern 37-11 Triplet Injection Completion

<table>
<thead>
<tr>
<th>Completion</th>
<th>OOIP (MSTBO)</th>
<th>Average Injection (RBPD)</th>
<th>Processing Rate (%HCPV/Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cisco</td>
<td>3255</td>
<td>5452</td>
<td>41%</td>
</tr>
<tr>
<td>GZ/UMCN</td>
<td>5845</td>
<td>6242</td>
<td>26%</td>
</tr>
<tr>
<td>LMCN</td>
<td>3121</td>
<td>1055</td>
<td>8%</td>
</tr>
<tr>
<td>Total</td>
<td>12221</td>
<td>12750</td>
<td>25%</td>
</tr>
</tbody>
</table>

![Diagram showing CO2 and Water injection for Cisco, Green Zone, and Middle Canyon completions.](image-url)
SACROC Pattern 37-11

**Oil Rate (BOPD)**
- Actual BOPD
- Actual BWPD
- Actual CO2p MCFD

**CO2 Production (MSCFD), Water Production (BWPD)**
- Total Pattern CO2 Inj Rate
- Lower Middle Canyon
- Green Zone
- Cisco
SACROC Platform Oil Rate Tests 10/2013
• Drilling a horizontal producer replaced drilling 5 vertical wells
  • Well was completed using 18 cross-linked gelled acid stages

• Being able to drill horizontal producers will reduce the development cost of expanding the CO2 flood project into the thinner patterns along the edge of the field
Lower MCN Horizontal Injection Completions

- Concerns over Lower MCN vertical well drilling costs, reservoir processing rates led to approving 6 horizontal injection wells in the P3 South and P3 North CO2 Flood Project Areas
  - Vertical well Lower MCN processing rates estimated to be <10% HCPV/yr
  - Multi-stage acid fractured Lower MCN processing rate expected to be >25% HCPV/yr
- All 3 of the P3 South wells have been successfully drilled and completed
  - 11-16H began water injection on 11/12/13; currently injecting 18,000 BWIPD
1996-2013 CO2 Flood Project Area Contribution to Total Unit Production
Future SACROC CO2 Flood Development

4-Component Strategy:

– Exploit Transition Zone
– By-Passed Redevelopment
– Edge Pattern Development
– Reassessment of Infill Development Potential
• Target zone is 9' below top of MCN2.
• Top of MCN2 is 8' below MCN3 (yellow zone)
  • Chevron OWC = dashed blue line
  • -4600ss is base of log tracks
Center Ring 1 & 2 Bypassed Pay
12-Horizontal Well Redevelopment Area
Potential CO2 Flood Expansion Patterns

- Although pay quality is less favorable, significant OOIP (>500 MMSTBO) exists outside the active or currently proposed project areas.
- Challenges to developing these patterns include:
  - Few if any available well bores
  - Insufficient pay volume to economically justify traditional pattern development
- Potential solutions being evaluated include:
  - Multi-stage fracture stimulated horizontal producers and injectors
  - Including Transition Zone reservoir volumes in recovery forecasts
  - Identifying areas that water flooded well, indicating they will respond well to CO2 injection
IDEA versus Offset Project Recoveries

IDEA Pattern recoveries to date are around 3% higher than in offset areas.

Although initially plagued by CO2 breakthrough problems, the combination of 10-acre infill drilling polymer gel and specialized cement squeeze treatments may have resulted in high efficiency patterns.

Some improved recovery due to targeting geologically isolated “Green Zone” Pinchouts.

Additional infill wells have been recommended.
Summary

• CO2 flooding has presented SACROC’s operators with engineering challenges since 1972

• Focused CO2 flood development projects, injecting large pore volumes of CO2 of 80-100% of the HCPV, have resulted in significant incremental EOR

• Mitigating heterogeneity issues through the innovative application of polymer, cementing, and horizontal well technologies has been critical to CO2 flood performance success

• Continued CO2 flood development of the lower permeability bypassed pay and reservoir around the edges, along with focused vertical/horizontal infill drilling applications within existing flood areas, will challenge SACROC engineers & geoscientists for many years to come

Big fields keep getting bigger!