Rejuvenating A Mature EOR Asset: Miscible CO₂ Flooding at SACROC

Mark Linroth
Kinder Morgan CO₂ Company, LP
December 7th, 2012
SACROC Unit (Canyon Reef)

- Discovered – Nov, 1948
- Formation – Canyon Reef (Limestone)
- Depth – 6200-7000 ft.
- OOIP – 2.8 BSTB
- Porosity – 9%
- Permeability – 30mD
- Reservoir Temp – 125°F
- Drive – Solution Gas
- Gravity – 42°API

- Disc Pressure – 3300 psig
- P_b – 1800 psig
- R_{si} – 1000 scf/bbl
- B_o – 1.65 rb/stb
- Viscosity – 0.33 cP
- S_{oi} – 80%
- S_{orw} – 35%

- MMP – 1850 psig
SACROC Unit (Canyon Reef)

- Discovered - Nov 1948
- Formation – Canyon Reef (Limestone)
- OOIP – 2.8 BSTB
- Gravity – 42°API
- Porosity – 9%
- Permeability – 30mD
- Reservoir Temp – 130°F
- Depth – 6200’
- $V_{dp}$ – 0.85
- Disc Pressure – 3300 psig
- $R_{si}$ – 1000 scf/bbl
- $B_o$ – 1.65 rb/stb
- Viscosity – 0.33 cP
- $S_{oi}$ – 80%
- $S_{orw}$ – 36%
- $P_b$ – 1800 psig
- MMP – 1850 psig
- Drive – Solution Gas
Regional & Geologic Setting

Hockley  Lubbock  Crosby  Dickens

Terry  Lynn  Garza  Kent

Gaines  Dawson  Borden  Scurry

Wellman Field  S. Brownfield Field  S. Von Roeder Field  Oceanic Field  Vealmoor Field

Horseshoe Atoll

Kelly-Snyder Field  Cogdell Field  S. Von Roeder Field  Sharon Ridge Unit  SACROC Unit

500'  500'

0 20 Miles

Oklahoma  Texas  Midland Basin
SACROC Unit Structure
SACROC Production Plot to 2001
November 1948

- 66 BOPD
- Water Cut 0%
- $N_p - 2,000 \text{ STB}$
November 1950

- 112,000 BOPD
- Water Cut 1%
- $N_p - 28$ MMSTB
- RF - 1%
November 1954

- 52,000 BOPD
- Water Cut 9%
- $N_p$ - 129 MMSTB
- RF – 4.6%
November 1971

- 134,000 BOPD
- Water Cut 27%
- $N_p - 528$ MMSTB
- RF – 19%
May 1972

- 175,000 BOPD
- 174 MMSCF CO$_2$
- Water Cut 36%
- $N_p$ - 552 MMSTB
- RF – 20%
May 1974

- 211,000 BOPD
- 150 MMSCF CO$_2$
- Water Cut 36%
- $N_p$ - 680 MMSTB
- RF – 24%
February 1995

- 10,000 BOPD
- 49 MMSCF CO₂
- Water Cut 97%
- N_p - 1,223 MMSTB
- RF – 44%
- 1st Truly Miscible
April 2000

- 8,400 BOPD
- 118 MMSCF CO₂
- Water Cut 95%
- \( N_\rho \) - 1,239 MSTB
- Cum CO₂ – 1.3Tcf
October 2001

- 9,000 BOPD
- 136 MMSCF CO₂
- Water Cut 95%
- $N_p$ - 1,244 MSTB
The Opportunity

• Saturation, Containment, Pressure, Injectivity, Connectivity

• Low CO₂ Injection Purchases
  – Over-distributed available CO₂
  – Resulted in low injection pressure

• No “Classic” Miscible CO₂ Flood Response
  – Water decreasing & CO₂ increasing

• THE CO₂ WAS NOT MISCIBLE
  – Swelled the Oil
  – Reduced Viscosity
  – IFT ≠ 0
The Opportunity

Slim-Tube Tests
MMP 1,746 psi at 120°F, 100% CO₂
MMP 1,751 psi at 120°F, 10% HCGas and 90% CO₂
MMP 2,104 psi at 120°F, 25% HCGas and 75% CO₂
At this rate & current oil price the field is uneconomic.

The previous immiscible flood recovered little oil beyond secondary

Can we improve the recovery with a fully miscible CO₂ flood?
Favorable Factors

- High K – means fast processing rates (~25%/yr)
- Low viscosity oil – 0.33 cP (favorable mobility ratio)
- Depth – Deep enough for miscibility, not too hot
- Known lithology – clean limestone, 100% Calcite
- Large unit – able to expand by phases
Operational Changes

• Raise average reservoir pressure above MMP

• Convert rod pump to ESP to maintain higher $P_{wf}$ (objective to prevent loss of miscibility near wellbore)

• Use active water curtain to prevent external migration of $\text{CO}_2$
Operational Changes (cont.)

• Extend initial CO$_2$ slug, follow with dry WAG (many patterns were WAG sensitive and premature water injection led to loss of recovery)

• All injectors completed cased hole to control vertical conformance.

• SIGNIFICANT increase in CO$_2$ purchases
SACROC CO$_2$ Project Areas

- 16 Phases to date
- Avg. Dim. Oil recovery $\sim$ 8.1%
- Avg dim CO$_2$ injected $\sim$ 0.55
Dim. Oil Recovery Curves
AFE vs. Actual Example

South Platform Oil Production

- Actual
- AFE
- Prior View ('11 Bud)
- Current View (3Q EG)

South Platform CO₂ Injection

- Actual
- AFE
- Prior View ('11 Bud)
- Current View (3Q EG)
Major Divisions

The Canyon Reef is divided up into four major divisions

• Cisco
• Green Zone
• Upper Middle Canyon
• Lower Middle Canyon

These are further subdivided into zones following the BEG convention
Dim oil Recovery vs. dim CO₂ Inj.

SACROC Cisco %EOR vs %HCPV CO₂ Injected

SACROC Green Zone %EOR vs %HCPV CO₂ Injected

SACROC Upper Middle Canyon (MCN3) Zone %EOR vs %HCPV CO₂ Injected

SACROC Lower Middle Canyon Zone %EOR vs %HCPV CO₂ Injected

Allocated Cisco %OOIP EOR Recovery (Based on Injection Profiles)

Allocated Green Zone %OOIP EOR Recovery (Based on Injection Profiles)

Allocated MCN3 Zone %OOIP EOR Recovery (Based on Injection Profiles)

Allocated Lower Middle Canyon Zone %OOIP EOR Recovery (Based on Injection Profiles)

Allocoated Pattern Cisco %HCPV CO₂ Injected

Allocated Pattern Green Zone %HCPV CO₂ Injected

Allocated Pattern MCN3 Zone %HCPV CO₂ Injected

Allocated Pattern Lower Middle Canyon Zone %HCPV CO₂ Injected

Recovery

SCALEUP

Bullseye Patterns

A = 0.275 D = 0.446 K = 1.05 Ar = 0.00046 C = 1.276 W = 0.001

A = 0.275 D = 0.446 K = 1.05 Ar = 0.00046 C = 1.276 W = 0.001

A = 0.275 D = 0.446 K = 1.05 Ar = 0.00046 C = 1.276 W = 0.001

A = 0.275 D = 0.446 K = 1.05 Ar = 0.00046 C = 1.276 W = 0.001
Oil Rate vs. Time

SACROC Unit Pattern PAT 58-2A

- Actual BOPD
- Forecast BOPD
- Base Case, BOPD
- Forecast BOPD
- Cumul EOR Oil (MSTBO)
- Forecast Cumul Oil (MSTBO)
- Base Case Cumul. MSTBO
- Forecast Cumul Oil (MSTBO)

+25 BOPD
CO₂ Produced vs. Time

SACROC Unit Pattern PAT 58-2A

- Actual CO₂ p MCFD
- Forecast CO₂ MCFD
- Base Case MSCFD
- Forecast CO₂ MSCFD
- Cumul CO₂ Prod (MMSCF)
- Forecast Cumul CO₂ Prod (MMSCF)
- Base Case Cumul. MMSCF
- Forecast Cumul CO₂ Prod (MMSCF)
Monitoring Tools

Injection Profiles
• Used to determine zone(s) of injection
• Run once per year on each fluid

Step-rate tests
• Used to determine parting pressure
• Run once per year on water injectors
Vertical Conformance

- Injector-Producer cross section showing dominant injection into one zone
- Significant amount of by-passed pay
284-4 Before and After Plugback
Conformance Response (212-2, 215-2 Polymer Jobs)

212-2 Job cost: $185,025
215-2 Job cost: $405,173

209-1 Production response
5 BOPD to 36 BOPD

212-1 Production response
8 BOPD to 100 BOPD
Step-Rate Test
Areal Conformance

- Pressure & Rate re-balancing
- Attempts to viscosify CO₂ – Surfactant pilot project
Examples of Pressure Re-balancing

Pattern production responded after 8 months drawdown of prior water curtain
November 2007

Note streamlines show no support to 261-3
Note streamlines now show 261-3 receiving support
BHP Monitoring

All ESP’s are equipped to record $P_{wf}$ and motor temp.

This data is available in real-time and can also be used to track reservoir pressure.
CTF Pressure & Rate Response in Offset Wells

PIP increase due to CTF in 288-1

Production response 200 BOPD and lower GOR below 20,000
Pattern 210-5 Rebalancing

- Incremental Oil Response
- Needs ESP Upsize
- High GOR Well CTF/SI as Required
SACROC Unit Structure
Un-Drained Pinnacles

Mae Lemens # 4
295-4
10/27/1950
<3,391FT>

SACROC UNIT
291-5
3/9/2011

Subsea Depth(ft)
-4250 ~
-4350 ~
-4450 ~
-4550 ~
-4650 ~

REEF_TOP

ECH

REEF_TOP

ECH

HS = 57
Un-Drained Pinnacles

Mae Lemens # 4
295-4
10/27/1950
<1,599FT>

SACROC UNIT
295-5
2/17/2011
<1,792FT>

SACROC UNIT
291-5
3/9/2011

Subsea Depth(ft)
-4250 –

REEF_TOP

ECII

Subsea Depth(ft)
-4250

-4350 –

-4450 –

-4550 –

-4650 –

HS= 57
CO$_2$ “Harvest” -- RTP
CO₂ “Harvest” -- Upsize
Production Response

Oil production rate has increased from 8800 BOPD to the current 30,000 BOBD.

Cumulative incremental oil production since year 2001 now exceeds 110 MMSTBO
Layer by Layer Forecasting Process

- Using the historical injection profiles determine the fraction of injected CO$_2$ entering each layer, and from the injection rate determine the %HCPV CO$_2$ injection with time into each layer.
- From the generalized dimensionless recovery curves we calculate the dimensionless oil and CO$_2$ recoveries for each layer.
- The Oil recovery equation “A” value is set to 15% initially, but it occasionally requires changing to “history match” performance.
- Calculate the oil and CO$_2$ production rates from the layer allocated CO$_2$ injection rate and the oil & CO$_2$ recovery derivatives.
- Sum the layer oil & CO$_2$ production rates to get the pattern oil & CO$_2$ production. Calculate the water production by material balance.
Outline

• Field History
  – Geologic Setting
  – Key Statistics
  – Production History

• The Opportunity

• The Challenge
  – Operational Changes
  – Monitoring
  – Rate Re-Balancing
  – Conformance