Integrated Reservoir Study for Designing CO$_2$-Foam EOR Field Pilot

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Outline

- Pilot Program
- Field Overview
- Laboratory Studies
- Reservoir Modelling & Simulation
- Conclusion
Pilot Program

OBJECTIVE

Cost-effective roadmap for mobility control CO\textsubscript{2} EOR implementation on Norwegian Continental Shelf through onshore field trials in Texas, USA

- Foam for Mobility Control

\textit{Gravity segregation  
Reservoir heterogeneity  
Viscous instability}
Multi-scale Approach
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Field Overview

- Mature carbonate reservoir
  - Remaining oil saturation: 30 - 40%

**Historical Production**

- **Infill Drilling**
- **CO₂ Injection**
- **CO₂ breakthrough**

**Legend**

- Oil Rate (STB/D)
- Water-cut (%)
- Gas-Oil Ratio (Mscf/STB)

**Stages**

- Primary
- Secondary
- Tertiary
Pilot Site

- Focus on well pair I1 - P5
  - Part of 40-acre pattern
  - Short interwell distance
  - Representative geology
  - CO₂ breaks through within a year
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Laboratory Studies

- Steady-state foam rheology

\[ \text{Foam quality, } f_g = \frac{V_{\text{gas}}}{V_{\text{gas}} + V_{\text{liquid}}} \]

Laboratory Studies

- Foam quality scan

**Fixed Total velocity, Varying Foam quality**

- Gas velocity
- Liquid velocity
- Pressure gradient (psi/ft)
- Apparent Viscosity, cP

- High quality
- Low quality
Foam Model

- Empirical model

\[ k_{rg}^f = k_{rg}^{nf} \times FM \]

\[ FM = \frac{1}{1 + fmmmob \times \left( 0.5 + \frac{\arctan[epdry(S_w - fmdry)]}{\pi} \right)} \]

Gas permeability in **presence** of foam

Gas permeability in **absence** of foam

Moobility Reduction Factor
Foam Model

- Parameters for pilot-scale simulation

![Diagram showing apparent viscosity vs foam quality with data points and an empirical model curve.]

- $fmmob = 180$
- $fmdry = 0.4$
- $epdry = 10000$
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Reservoir Characterization

- Available data
  - Petrophysical well logs
  - RCA (porosity, permeability, Sw)
  - Core photo (for 1 well in pilot area)
- Cyclical sequence of carbonate rocks
  - Consists dolostones, packstones and grainstones
- Geologic framework based on flow zones and cyclicity
Geologic Model

- Spatial distribution of petrophysical properties using stochastic simulation

85,000 active cells
50 ft x 50 ft areally

Permeability
PVT Model

- PR EoS (8 components) tuned for available PVT data

*Circle represents Measured data, Line represents EoS calculation
Simulation Model

Geomodel

PVT Model

Relative Permeability

Foam Model

Well Inflow

Local Grid Refinement
Historical Water Injection

- BO Model (Includes peripheral injectors)
- Focus on updating volumes, and interwell permeability
Waterflood Match: Cum Oil Produced

- Extended Model
  - Base
  - Observed
  - HM

- Graphs for P6 (l1), P1, P3, P4, P5
CO₂ Injection Simulation

- 4 years of CO₂ injection
  - Gas b/t in all pilot producers

- Compositional model
  - Composition based on PVT report

- Initialization from HMed waterflood
  - Pressure and Saturation (O/W)

- History matching in progress...
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Summary

- Foam behaviour at core scale captured using fit-for-purpose lab studies and models
- An integrated approach for reservoir modelling and simulation allows to incorporate all available data

Looking ahead
- Calibrate model for CO$_2$ injection period
- Baseline survey
- Optimal injection strategy
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Waterflood Match: Water-cut

L12

Base

HM

Observed

L14

L21

L25

L32
Waterflood Match: Permeability change

Layer - 4
Base PermX
PermX Change

Layer - 7

Layer - 8
Waterflood Match: Permeability change

Layer - 10

Layer - 16

Layer - 19

Base PermX

PermX Change
Reservoir Pressure on higher side!
Reservoir Setup

- 2 zones because of structural tilting / seal breach event:
  - MPZ (Main Pay Zone)
    - Primary & Secondary recovery
  - ROZ (Residual Oil Zone)
    - Large amount of immobile oil (20-40%)

Zones differ in fluid composition
Well Connectivity

** from start of CO2 injection: Oct 13
** from start of CO2 injection in L-13: Jan 16