CO$_2$-EOR Reservoir Workflow

2nd Biennial CO$_2$ for EOR as CCUS Conference

Metin Karakas

Houston, TX
October 5, 2015
RMC Objectives

- Identify current key technology gaps
- Focus on interfaces between different disciplines
- Integrate data, information, expertise and workflows
- Maintain a balance between the short term high impact research and long term needs
- Develop dynamic reservoir monitoring (DRM) workflows
- Focus areas:
  - Shale,
  - Carbonate,
  - Deep water
Faculty & PhD Students

- Prof. Aminzadeh (Principal Director)
- Prof. Ershaghi
- Prof. Jessen
- Prof. Jafarpour
- Dr. Yesser Haj Nasser (Post Doc)
  - Magdalene Ante (NETL)
  - Ahmed Bubshait (Saudi Aramco)
  - Mehran Hosseini
  - Nima Jabbari
  - Metin Karakas (Chevron Fellowship)
  - Debotyam Maity (now with Gas Technology Institute)
  - Noha Najem (Kuwait Oil Company)
  - Arman Nejad
  - Mahshad Samnejad
  - Tayeb Tafti (now with Aera Energy)
  - Robert Walker (Chevron Fellowship)
USC Reservoir Monitoring Consortium

RMC Base Projects

- Optimize Hydraulic fracturing for shale
- Physical Models to monitor reservoir fluid (with CUP)
- MEQ to Map Reservoir Structure
- Time lapse Petrophysics for RM
- MEQ & Seismic Integration for Shale Reservoirs
- Tomography Based Reservoir Modeling
CO$_2$-EOR Research Objectives

- To conduct a through research to understand how we could mitigate the undesirable effects during CO$_2$-EOR implementations
- To understand the CO$_2$ fluid flow behavior under adverse reservoir conditions (layering, gravity segregation)
- To assess the relative merits of various measurements (well testing, Seismic & EM surveys) to map the fluid fronts
- To come up with a practical workflow to reduce the uncertainty by combining these measurements
Successful CO$_2$ - EOR Projects

- Reservoir, Fluid & Rock Characterization
- Reservoir Monitoring
- Data Integration
- Conformance Control
Reservoir Conformance

- Low reservoir sweep efficiency under conditions of high (unfavorable) mobility ratios
- Gravity override by the less dense CO2
- Viscous fingering of the CO2
- Channeling of the CO2 in highly heterogeneous reservoirs
Reservoir Workflow

Target Areas for CO2 Pilot
- Saturation & Pressure Distributions
- Fractures, Risks & Opportunities

Screening Studies
- CO2 Core Tests
  - CO2 SCAL, Residual Oil Saturation
- Well and Completion Types, Injection Schemes, Mobility Control Agents
- Differential Fluid Movement, Facies, Vertical Barriers, High-Perm Streaks, Fracture Corridors

Reservoir Uncertainties
- Key Success Factors
  - Conformance, Residual Oil Saturation, Risks & Opportunities
- Residual Oil, Miscibility
- CO2 SCAL, Asphaltine, Foam Fluid & Rock Interactions

CO2 Fluid Characterization
- Representative Fluid Sample
- Multi-Contact Miscibility, Asphaltene Deposition during production

Tests under reservoir conditions
- Technical Success?

Sensitivity Studies
- Sensitivity Studies
  - Differential Fluid Movement, Facies, Vertical Barriers, High-Perm Streaks, Fracture Corridors
  - Key Success Factors Conformance, Residual Oil Saturation, Risks & Opportunities

Site Selection
- Residual Oil, Miscibility
- CO2 SCAL, Asphaltine, Foam Fluid & Rock Interactions

CO2 Fluid Characterization
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Pilot Design
- Observation Wells
  - Completion Types & Control, Reservoir and Well Monitoring, Mitigation Plans
- Reservoir & Well Monitoring
  - Injection & Production Control Mobility Reduction Real-time Model Update

Pilot Execution
- Pilot Evaluation
  - Lessons Learned Data Integration & Production Forecasting
  - Key Success Factors Met?

Sector / Field Development
- Sector Model Remaining Uncertainties
- Risk Mitigation, Opportunities
Reservoir Uncertainty

Ref: “A Pilot Carbon Dioxide Test, Hall-Gurrey Field, Kansas” by G.P. Willhite et. al. (2012)
Reservoir Workflow

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Technical Success?

Real-time Model Update

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Reservoir and Well Monitoring,
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Well and Completion
Types, Injection Schemes,
Mobility Control Agents

Site Selection

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Base Measurements

Time 1

Time 2

Key Success Factors Met?

Adequate Information?

control

update

invert

operate

forecast

optimize

apply
Cross-Well Testing
Ref: Karakas & Kristensen
(Slb, unpublished work - 2011)

- Pulses generated by step changes in injection rate
- Pressure monitored in observer
- Travel time and amplitude of pressure response recorded
- 3 scenarios:
  - Water injection
  - CO2 injection
  - CO2 WAG injection
- Compositional, 1D & 2D models, 2000-5500 blocks
- Initial reservoir pressure varied above/below MMP for CO2
$\text{CO}_2$: Miscible Case: $P > \text{MMP}$

**Gas Saturation**

- Saturation vs. Distance [ft]
- OB

**Total Mobility**

- Mobility [1/cP] vs. Distance [ft]
- OB

**Delta Pressure vs. Delta Time**

- Delta pressure [psi] vs. Delta time [days]
- @ pulse 1
- @ pulse 2
- @ pulse 3
- @ pulse 4

No change in time lag?
$CO_2$: Miscible Case: $P > MMP$

$t_D \propto \frac{S}{T} \\
S = \phi c_i h = \text{storativity} \\
T = \frac{kh}{\mu} = \text{transmissivity}$

Time lag $\sim \frac{\text{Compressibility}}{\text{Mobility}}$

- Change in mobility is offset by change in compressibility
- Therefore no observable change in time lag
Miscible CO$_2$ Injection

$K_v = 0.1 \text{mD}$

$K_v = 0.01 \text{mD}$

$K_v = 0.001 \text{mD}$

Gas Saturation
Miscible CO₂ Injection

Layer Injection profile:

- Q₁
- Q₂
- Q₃
- Q₄

Graphs showing Delta pressure [psi] against Delta time [days] for each layer, with different injection pulses.
Mobility Control

Permeability
- high
- low

No mobility control

Completions shut-off

Completions shut-off + mobility control agent
Seismic Response during Oil Injection

Fig. 9. (a) YZ distribution of AE hypocenters localized during fluid injection in Test #1. The color of the balls indicates time sequence of AE events appearance according to color bar at the bottom of Figure 9a. The diameter of the balls is proportional to the logarithm of AE amplitude; (b) the photo fracture surface reviled after completion of Test #1, dark red color of oil indicates position of fluid front.

* Acoustic Emission and Ultrasonic Transmission Monitoring of Hydraulic Fracture Initiation and Growth in Rock Samples
Sergey STANCHITS, Aniket SURDI, Eric EDELMAN, Roberto SUAREZ-RIVERA
Conclusions

- CO$_2$-EOR is the realistic way forward for CO$_2$ storage
- We need technologies and methodologies that can make difference (cost and containment)
- Petroleum Engineers can make a difference!
Thank you