The Eagle Ford Shale Laboratory: A Field Study of the Stimulated Reservoir Volume, Detailed Fracture Characteristics, and EOR Potential
Award No. DE-FE0031579

Texas A&M University
Lawrence Berkeley National Laboratory
Inpex Eagle Ford, LLC
Stanford University

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Stanford University
Eagle Ford Shale Laboratory (EFSL)

• **Research Team:**
  • Texas A&M University
  • Lawrence Berkeley National Lab
  • Stanford University
• **Operator:** Inpex Eagle Ford, LLC
• **Field Site:** Eagle Ford Shale near Los Angeles, TX (LaSalle County)
• **JIP participants:** CNOOC, ExxonMobil, Schlumberger
Site Location

Klattenhoff Unit LAS 1H
(Completed in 2012)
4,600' Lateral
28°27'08.5"N
98°59'40.2"W

New Wells
Shaw-Klattenhoff 1H-6H
Objectives of the Project

1. Perform high-spatial and -temporal resolution active and passive monitoring to image the stimulated reservoir volume (SRV) during fracturing, re-fracturing and gas-EOR processes.

2. Monitor long-term production (inflow profiles and bottomhole pressures) in producing and observation wells

3. Improve drilling efficiency

4. Optimize the fracturing process

5. Evaluate EOR in the field

6. Calibrate fracture/reservoir models
EFSL Main Tasks

• Phase I: Re-fracture monitoring and evaluation
• Phase II: Monitoring, evaluation and optimization of multistage fracture stimulation (three new producers)
• Phase III: EOR pilot with gas injection
Advanced Technologies

Extensive, robust, state-of-art monitoring, diagnosing and modeling abilities:

- Geosteering and Thru-bit monitoring during drilling
- Active seismic interrogation
- Permanent fiber optic sensing (DTS, DAS, DSS)
- Extensive logging for formation evaluation and fracture diagnosis
- Tracer evaluation of re-frac
- Downhole video of perforation erosion
- Vertical well cores for supporting lab work
- Theoretical and numerical modeling
Existing Site and Legacy Well

Klattenhoff Unit LAS 1H:
- Completed: July 2012
- Perforated Lateral: 4,481'
- Total Stages: 14
- Frac Fluid Volume: 15 bbl/ft.
- Proppant Mass: 646 lbm/ft.
- Cum Oil Production: 80,394 STB
- Current Water Cut: ~22%
Planned Wells (1H-6H)

Legend:
- **Shaw Unit**
- **Klottenhoff Unit**
- **Legacy Well**

Well spacing: 270'
Legacy Well Refrac

Borehole Monitoring Packages Including:
- Behind Casing Fiber Optics (DAS, DTS, DSS)
- Behind Casing P&T Gauge Array

Legacy Well
Phase 1 – During Re-fracture Treatment

- Surface seismic – Active sources to downhole DAS and geophone array
- DTS/DAS/DSS along entire HOW
- Pressure & temperature gauge array in horizontal observation well
- 3C geophone array deployed in HOW during fracturing
- Normal surface frac monitoring data
Phase 1 – During Re-fracture Treatment

- Frac fluid tracer – oil and/or water soluble tracers
- Post-frac logs in refrac well and 2H observation well
- Downhole video measurement of perforation erosion
**SOV/DAS for Seismic Monitoring**

**Target:**
- High-repeatability time-lapse seismic for monitoring fracture opening and closure in space & time.
- Provide an active source approach for quantifying the SRV

**Solution:**
SOV (Surface Orbital Vibrator) + DAS (Distributed Acoustic Sensing)

**Challenges:**
1. Is the data quality acceptable for seismic monitoring?
2. Is the acquisition system repeatable for seismic monitoring?

![Image](attachment:image.png)

*Figure 5. Zoom of north shot location shot gathers showing prefrac (a) baseline, (b) shot acquired after stage 33, and (c) the difference between the two. Black dashed line shows the timing of the direct P-wave arrival. Red arrow shows the location where stage 33 was fracked along the well.*

*Byerley et al. (2018)*
Conventional vs DAS Seismic Monitoring

Conventional campaign-based systems

SOV-DAS permanent monitoring system
Surface Orbital Vibrator – VFD Controlled AC Induction Motor

Max Frequency 80 Hz, Force (@80Hz) 10 T-f
Phase stability is not maintained

Force is adjustable

\[ F = m\omega^2 r \]
SOV Field Tests for EFSL

① WebDAQ geophone
② Foundation Installation
③ SOV
④ Control Electronics
⑤ Site map
SOV/DAS : Vertical Section

- Stacked gather (10 sweeps) of deconvolved SOV
- Just for vertical section of the well.
- Rich wavefield including direct/reflected P and S as well as both up and downgoing converted modes.
SOV monitoring status

• Our preliminary results indicate:
  • SOV/DAS provides a good alternative for true continuous monitoring at a low cost for unconventional reservoirs monitoring;
  • it enables high resolution seismic data acquisition in space & time, with high repeatability and good data quality.

• Our plan:
  • We will install engineered fiber cemented in the well along the vertical and horizontal sections
  • We plan to install an array of 8 SOVs
  • We will include static strain monitoring with Distributed Strain Sensing
• Current SOV deployment plan
• Modeling work underway to optimize locations for reflection imaging
Interpretation of Distributed Acoustic Sensors (DAS) and Distributed Temperature Sensors to for Fracture Diagnosis
DAS and DTS Waterfall Plots
Laboratory Experiments and Computational Simulations

Correlation between acoustic signals and fluid flow rates:

\[ \log(q^3) = A \times L_{SP} + B \]

where \( q \) is flow rate, \( L_{SP} \) is sound pressure level, \( A \) and \( B \) are parameters of the correlation.

![Diagram of fracture with microphones and log-log plot showing experiment vs simulation results]
Energy Response of Acoustic Signal

\[ \log(q^3) = A \times E + B \]

Frequency Band Energy (FBE):

\[ E = \sum_{j=1}^{N} x^2(j) \]

\( x(j) \) is sample \( j \) out of \( N \) samples in a fixed period of time (for example every 1 second).
The diagram shows the injected volume of fluid for different cluster numbers. The x-axis represents the cluster number, ranging from 1 to 4. The y-axis represents the injected volume, measured in barrels (bbl). The diagram compares two methods: DAS (blue bars) and DTS (red bars). For each cluster:

- Cluster 1: 5% DAS, 6% DTS
- Cluster 2: 18% DAS, 10% DTS
- Cluster 3: 55% DAS, 59% DTS
- Cluster 4: 22% DAS, 24% DTS
Laboratory Measurements of
• Propped Fracture Conductivity
• Relative Permeability
Measurement of Rock Properties with Drill Cuttings

- Nano-indentation
- Scratch tests
Gas Injection EOR Experiments
• Minimum Miscibility Pressure
• Wettabillity
• Spontaneous Imbibition
A graph showing the relationship between Test Pressure (psig) and Slim Tube Recovery Factor (%). The MMP is indicated as 2,132 psig.

A table for Doped Eagle Ford Crude Oil with Test Pressure (psig) and Oil Recovery (% of OOIP) for Miscible and Immiscible cases.

Miscibility Status
- Miscible: Test Pressure (psig) 4500, Oil Recovery 91.3%
- Immiscible: Test Pressure (psig) 2500, Oil Recovery 87.24%

Other Table Values:
- Res Temp (°F): 170
- MMP (psig): 2,132
Low Porosity CT #

Gas

Surfactant

High CT #
Smaller pores
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