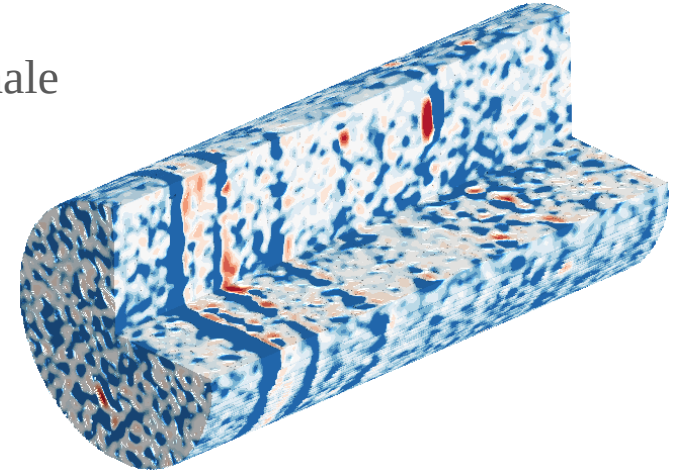
Preparations for Assessing Impact of CO_2 Flooding on Hydrocarbon Recovery in Nano-Darcy Shales

YOUSSEF ELKADY

2018 SCCS Affiliates, May 10th, 2018

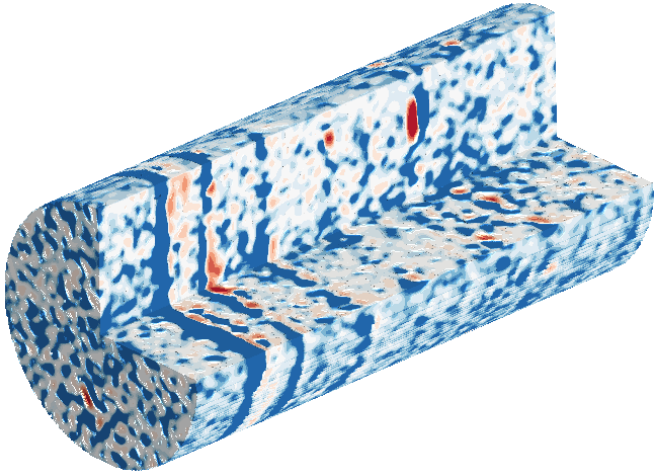
Outline

- Problem Introduction
- Objectives and Results
  - Porosity and Permeability Dependencies
  - CMG Validation
  - CO2 Recovery in Carbonate-Rich Nano-Shale
- Current Work
  - CO2 Experiment Initial Considerations
  - Preliminary results
- Future Work



Outline

- Problem Introduction



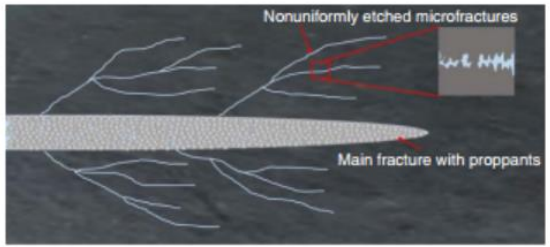
CO2/Acid Potential on Carbonates-Rich Shales?

- Gas potential: Marcellus, Barnett, and Haynesville alone ~ 2500 TCF (DOE/NETL 2009)
  - 20-30% recovery
- Oil potential: 4.9 MMBbl/d in 2015 about 52% US oil production (EIA, 2017)
  - 5-10% recovery

CO2/Acid Potential on Carbonates-Rich Shales?

- Gas potential: Marcellus, Barnett, and Haynesville alone ~ 2500 TCF (DOE/NETL 2009)
  - 20-30% recovery
- Oil potential: 4.9 MMBbl/d in 2015 about 52% US oil production (EIA, 2017)
  - 5-10% recovery

- Reason:

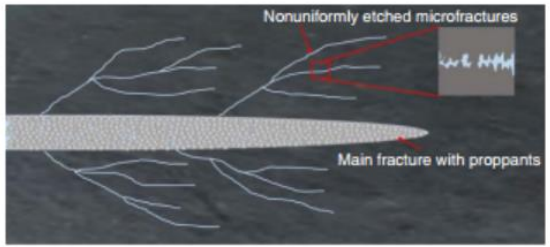


(Wu and Sharma, 2015)

Nano-Darcy k
Low porosity
Multi-phase blocking
Low matrix diffusivity

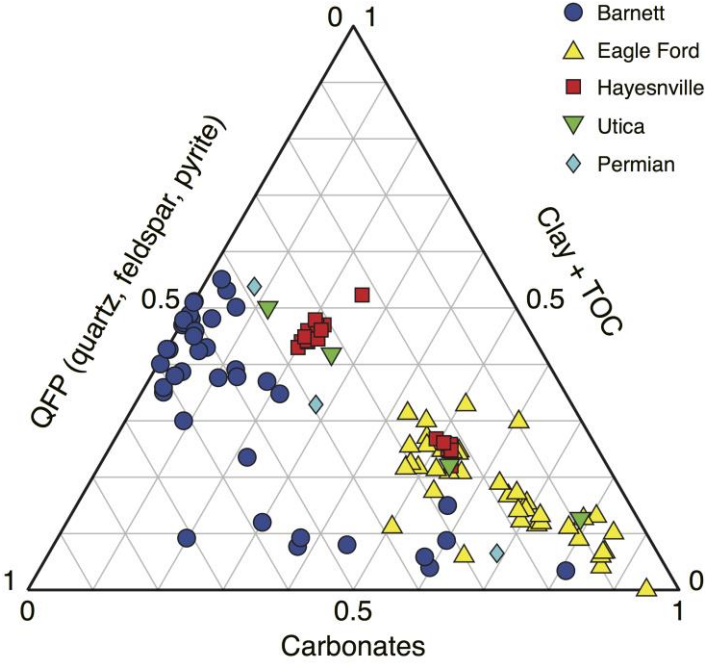
CO2/Acid Potential on Carbonates-Rich Shales?

- Gas potential: Marcellus, Barnett, and Haynesville alone ~ 2500 TCF (DOE/NETL 2009)
  - 20-30% recovery
- Oil potential: 4.9 MMBbl/d in 2015 about 52% US oil production (EIA, 2017)
  - 5-10% recovery
- Reason:



(Wu and Sharma, 2015)

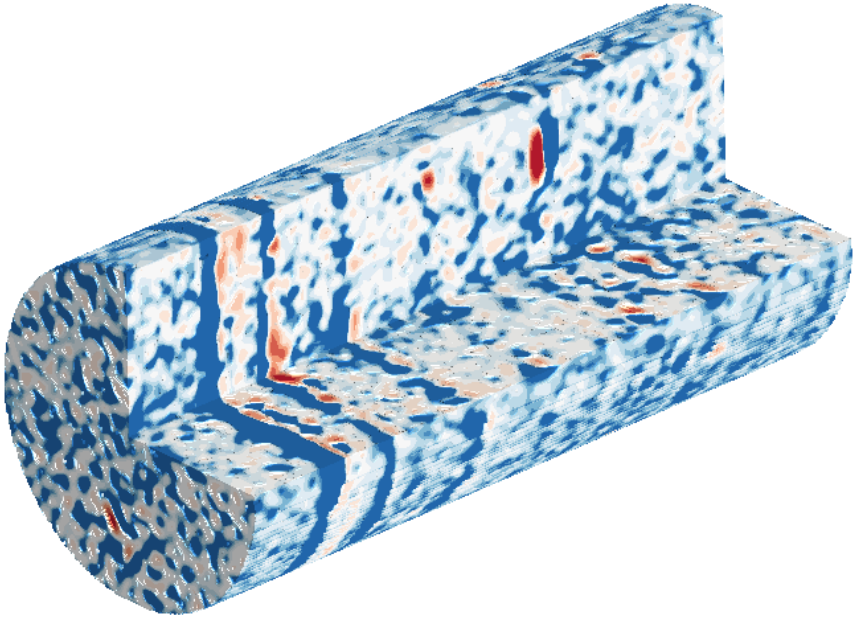
- Room for improvement:
  - pH of water in scCO2: 2.80 – 2.95
  - More accessibility relative to proppant



(Kohli, Unpublished)

Outline

- Problem Introduction
- Objectives and Results



Objectives

- Characterize rock and design testing geometries (Part I)
  - Characterize effective stress and pore pressure influence porosity and permeability
  - Different fracture geometries (Linear cut and triaxial complex fracture geometries)

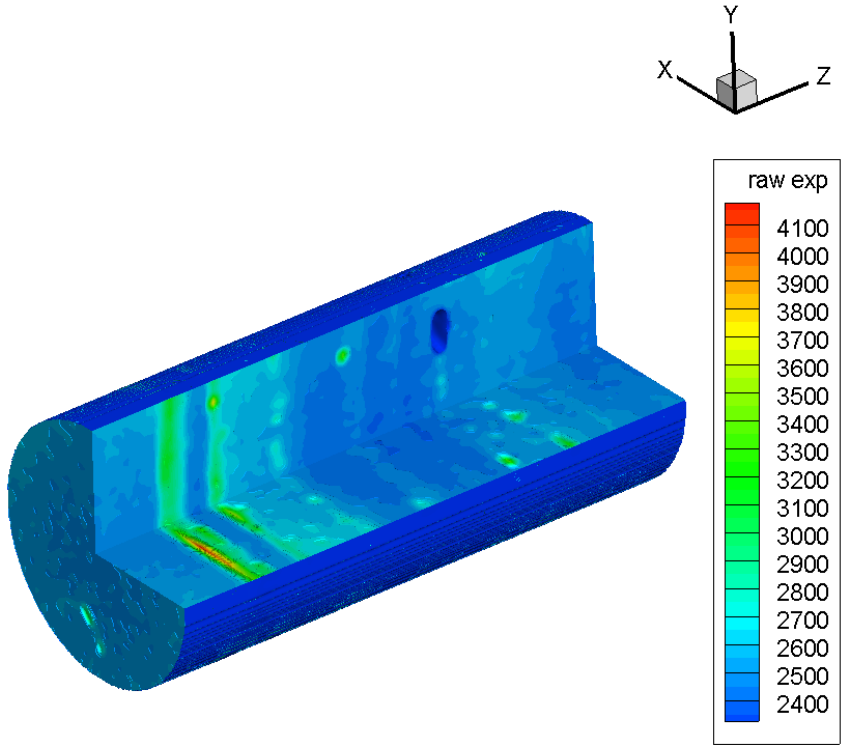
- Assess water-saturated supercritical (reactive) CO_2 influence on carbonate mineral rich shales (Part II)
  - Quantify additional recovery using huff and puff vs continuous injection scenarios
  - QXRD sampling for mineral alteration assessment before and after

- Develop core scale CMG STARS models for both intact and fractures cores matching pulse decay, core floods, and 3D Computed Tomography (CT) imaging results. Potentially expanding to field scale using E300 after matching model to experimental findings (Validation Component of Part I and II)

Investigated Core: QXRD and 3D CT Image

Mineralogy	%
Pyrite	1-2
Chlorite	0-1
Ankerite or Excess Calcium Dolomite	4-5
Calcite	50-60
Clay	20
Quartz	13

Mineralogy	Color
Pyrite	red
Ankerite or Excess Calcium Dolomite	green
Calcite	light blue
Clay and Quartz	dark blue



Objectives and Results – Part I

Concluded Work

Design Complete

- Investigate CO_2 EOR potential in nano-Darcy rock
  - Characterize effective stress and pore pressure influence porosity and permeability
  - Different fracture geometries (Linear cut and triaxial complex fracture geometries)

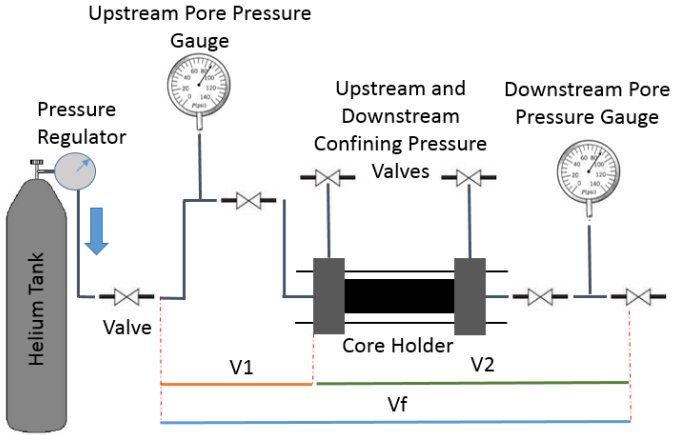
Objectives and Results – Part I

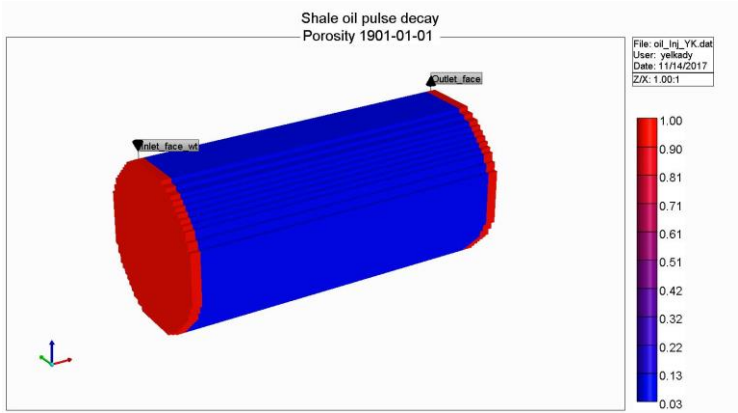
Concluded Work

Design Complete

- Investigate CO_2 EOR potential in nano-Darcy rock
  - › Characterize effective stress and pore pressure influence porosity and permeability
  - › Different fracture geometries (Linear cut and triaxial complex fracture geometries)

Results – Intact Rock





Experiment Pulse Decay CMG

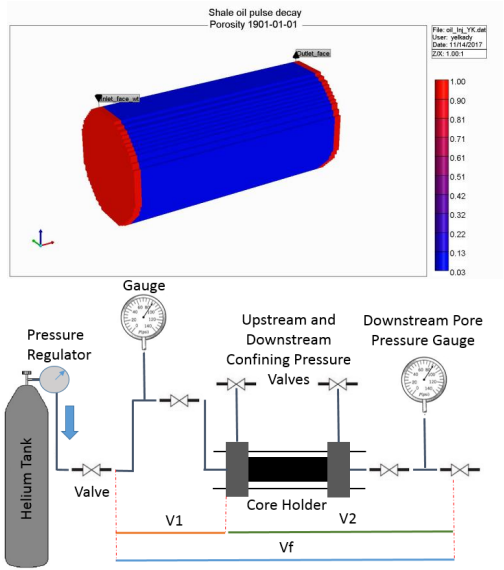
Objectives and Results – Part I

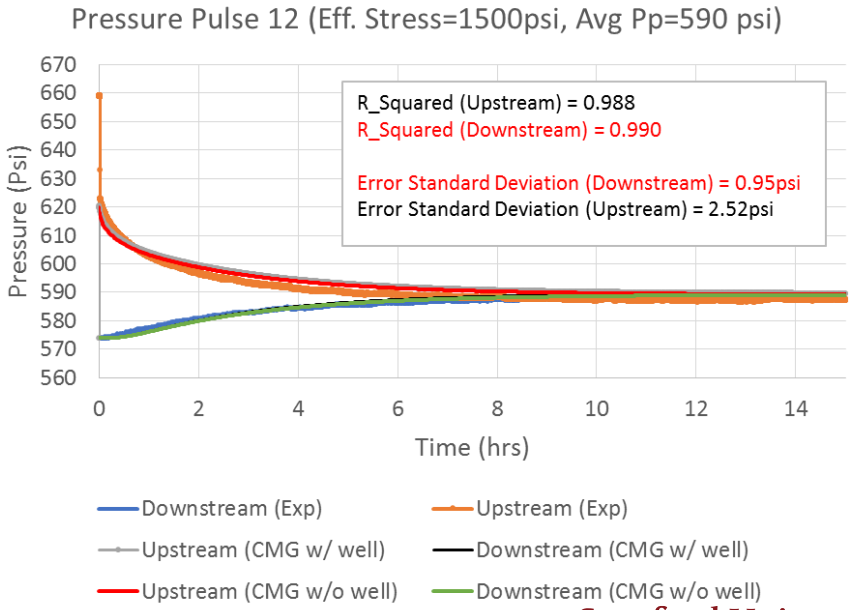
Concluded Work

Design Complete

- Investigate CO_2 EOR potential in nano-Darcy rock
  - › Characterize effective stress and pore pressure influence porosity and permeability
  - › Different fracture geometries (Linear cut and triaxial complex fracture geometries)

Results – Intact Rock





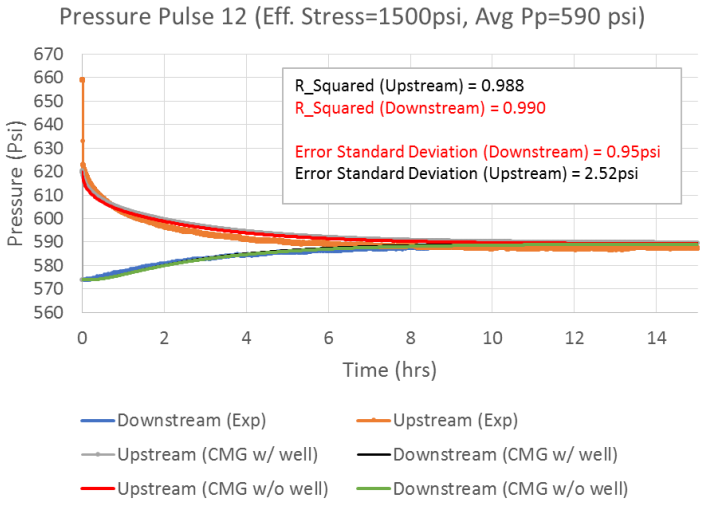
Objectives and Results – Part I

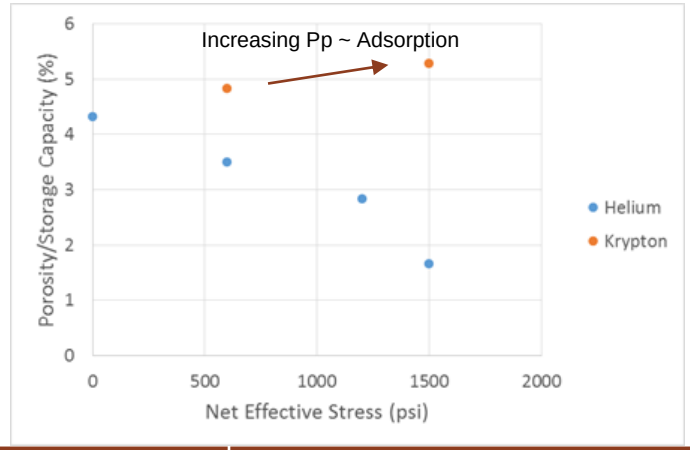
Concluded Work

Design Complete

- Investigate CO_2 EOR potential in nano-Darcy rock
  - Characterize effective stress and pore pressure influence porosity and permeability
  - Different fracture geometries (Linear cut and triaxial complex fracture geometries)

Results – Intact Rock





Effective Stress (Psi)	Liquid-like vertical permeability (nD)
300	1000
600	840
1500	50

Objectives and Results – Part I

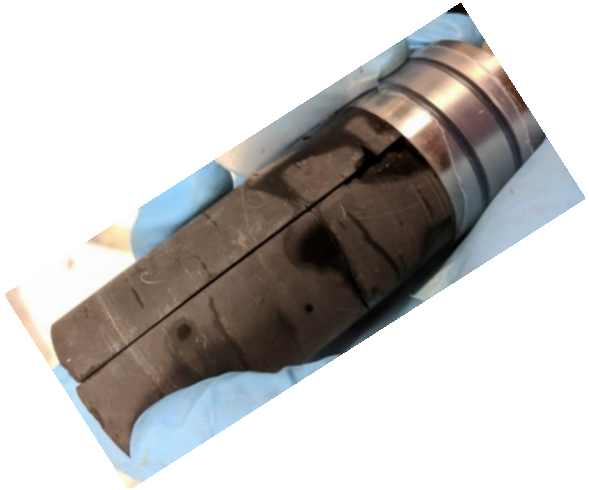
Concluded Work

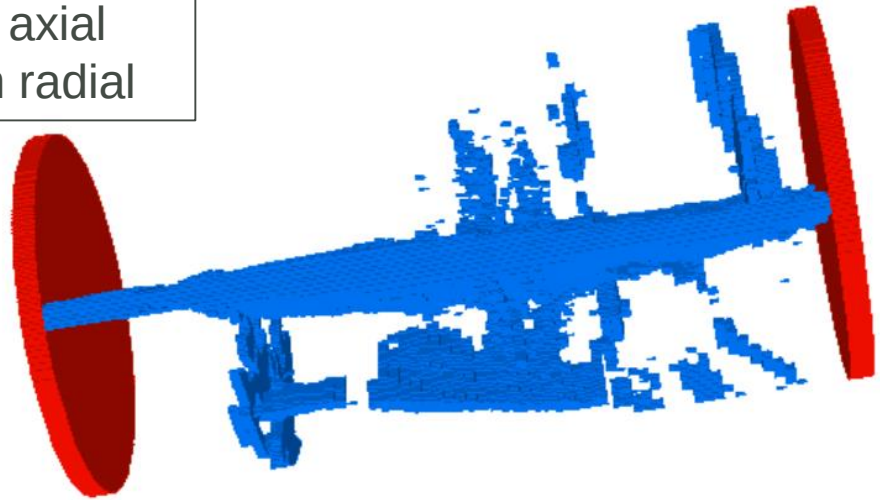
Design Complete

- Investigate CO_2 EOR potential in nano-Darcy rock
  - Characterize effective stress and pore pressure influence porosity and permeability
  - Different fracture geometries (Linear cut and triaxial complex fracture geometries)

Results – Linear Cut

CT Resolution
~ 2 million cells
1mm axial
0.2mm radial





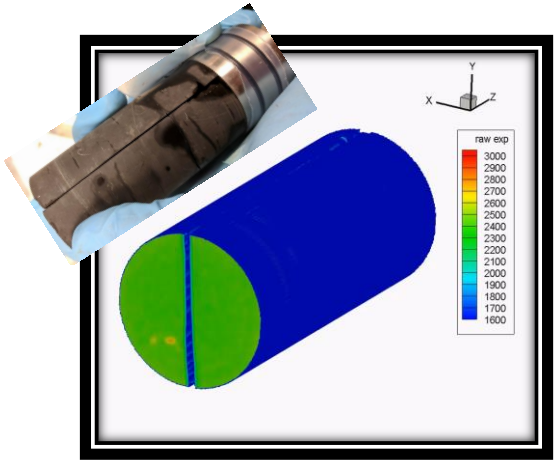
Objectives and Results – Part I

Concluded Work

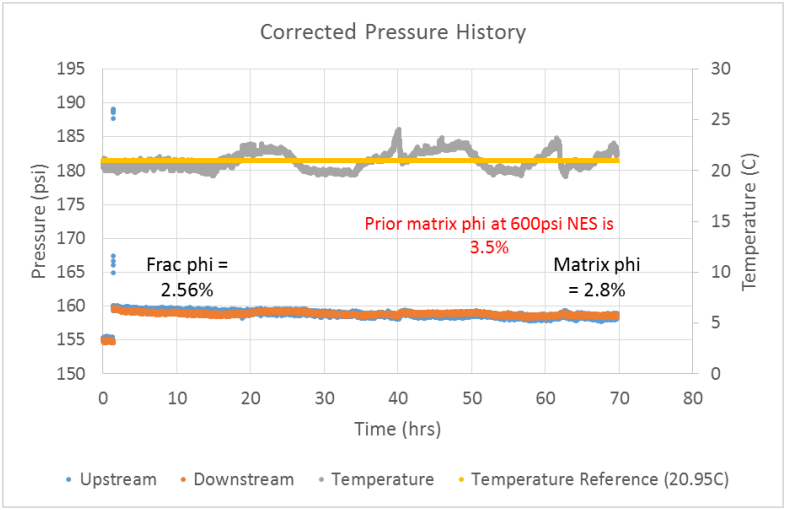
Design Complete

- Investigate CO_2 EOR potential in nano-Darcy rock
  - › Characterize effective stress and pore pressure influence porosity and permeability
  - › Different fracture geometries (Linear cut and triaxial complex fracture geometries)

Results – Linear Cut



Helium
Pulse Decay
@ 500 NES
(Future Oil Recovery
Experiment)



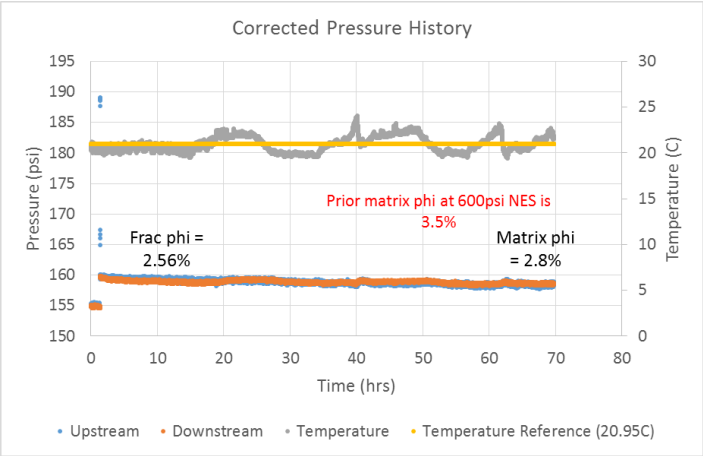
Objectives and Results – Part I

Concluded Work

Design Complete

- Investigate CO_2 EOR potential in nano-Darcy rock
  - Characterize effective stress and pore pressure influence porosity and permeability
  - Different fracture geometries (Linear cut and triaxial complex fracture geometries)

Results – Linear Cut



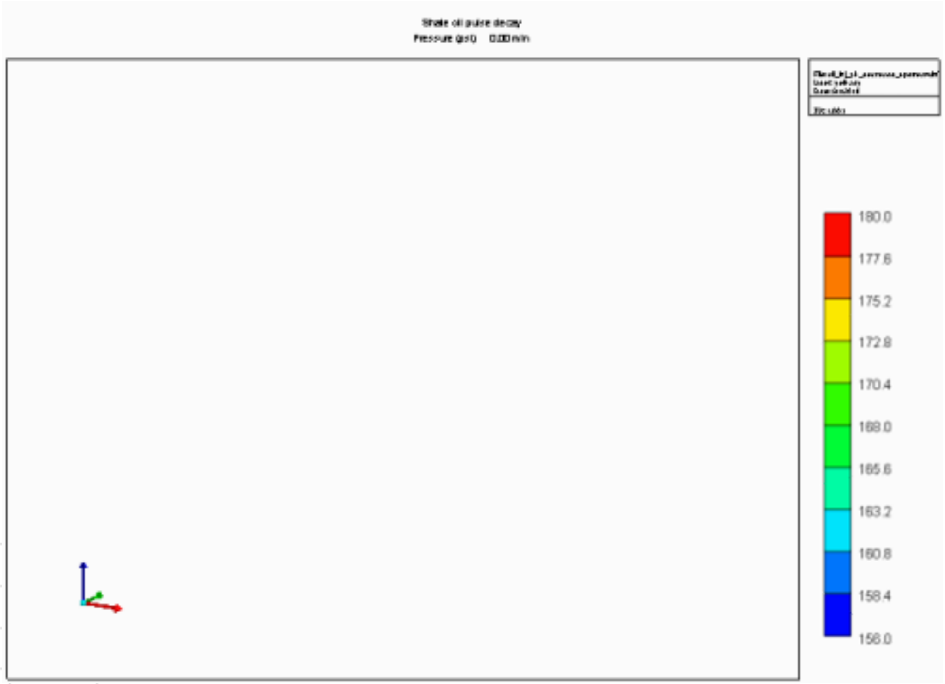
Two Independent Experiments

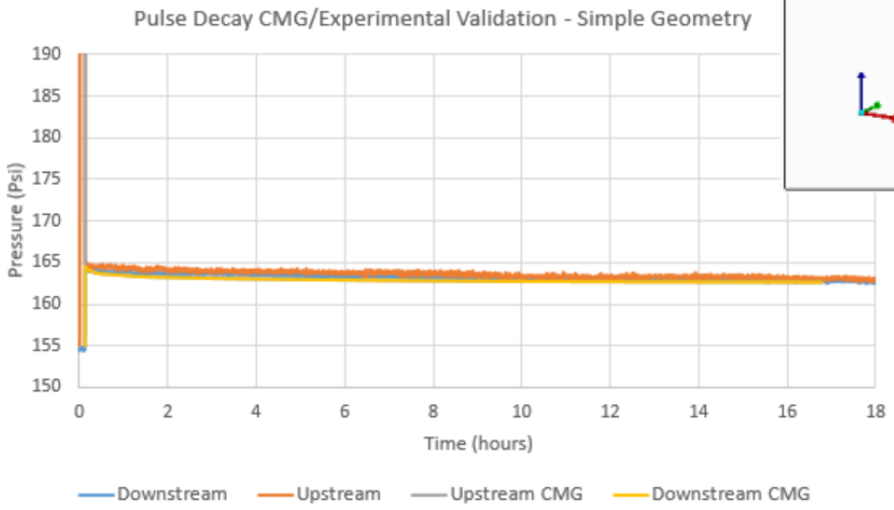
<u>Permeability:</u>
Pulse 1 → 2.5nD
Pulse 2 → 2.5nD

<u>Porosity:</u>
Pulse 1 (70hrs) –
Frac: 2.56% Matrix: 2.8%
Pulse 2 (240hrs) –
Frac: 2.3% Matrix: 3.6%

Objectives and Results – Part I

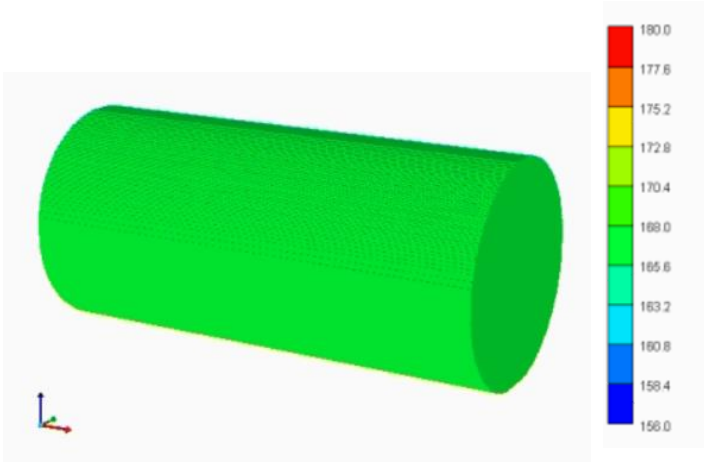
- Fracture porosity and matrix permeability validated
- Matrix porosity in progress

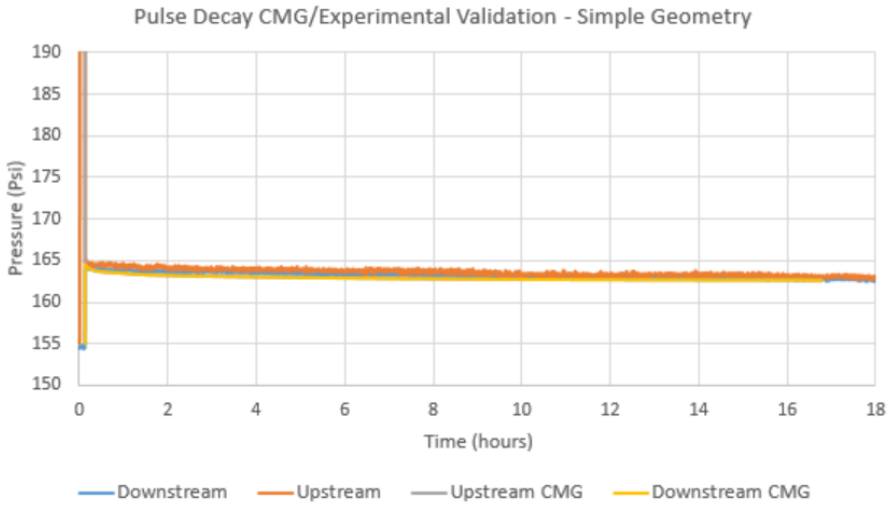




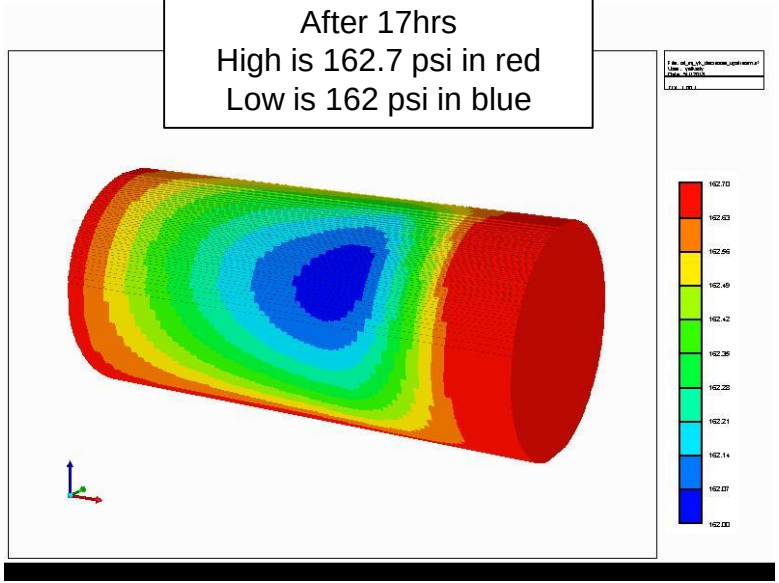
Objectives and Results – Part I

- Fracture porosity and matrix permeability validated
- Matrix porosity in progress





After 17hrs
High is 162.7 psi in red
Low is 162 psi in blue



Objectives

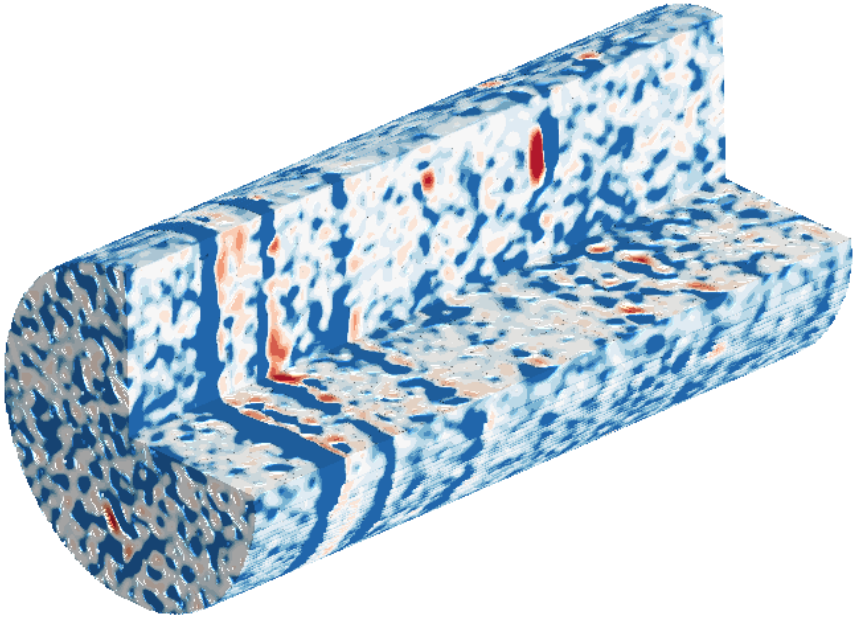
- Characterize rock and design testing geometries
  - Characterize effective stress and pore pressure influence porosity and permeability
  - Different fracture geometries (Linear cut and triaxial complex fracture geometries)

- Assess water-saturated supercritical (reactive) CO_2 influence on carbonate mineral rich shales
  - Quantify additional recovery using huff and puff vs continuous injection scenarios
  - QXRD sampling for mineral alteration assessment before and after

- Develop core scale CMG STARS models for both intact and fractures cores matching pulse decay, core floods, and 3D Computed Tomography (CT) imaging results. Potentially expanding to field scale using E300 after matching model to experimental findings

Outline

- Problem Introduction
- Objectives and Results
- Current Work



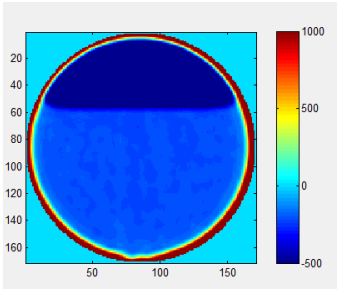
Current Work – Part II

- Assessing CO2 Recovery
  - Saturating nano-Darcy core with oil
    - Setup pressure limit → maximize injectivity
    - Miscibility pressure of oil/CO2 → eliminating capillary pressure
  - Measuring initial oil saturation
    - Mass balance (small volumes → large error)
    - CT method

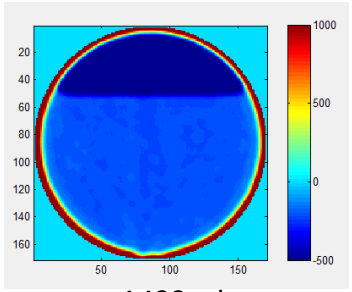
- Quantifying Mineralogical Alteration
  - Sample perpendicularly from fracture surface for QXRD

Current Work – Part II

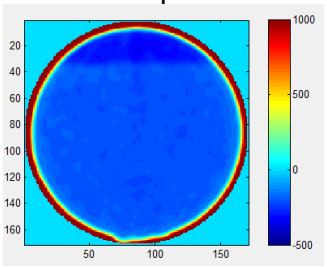
- Assessing CO2 Recovery
  - Saturating nano-Darcy core with oil
    - Setup pressure limit → maximize injectivity
    - Miscibility pressure of oil/CO2 → eliminating capillary pressure



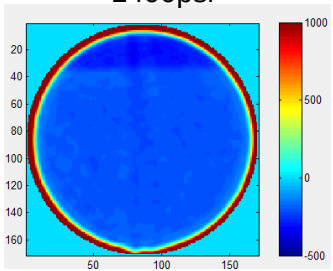
1000psi



1400psi



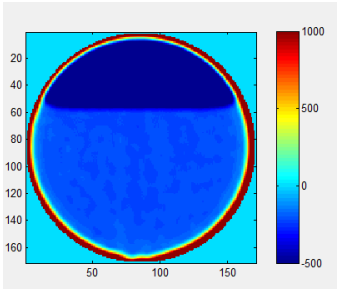
1750psi



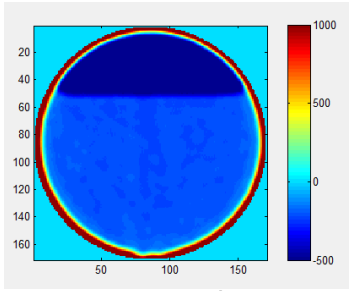
1850psi

Current Work – Part II

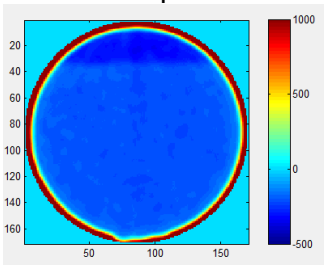
- Assessing CO2 Recovery
  - Saturating nano-Darcy core with oil
    - Setup pressure limit → maximize injectivity
    - Miscibility pressure of oil/CO2 → eliminating capillary pressure



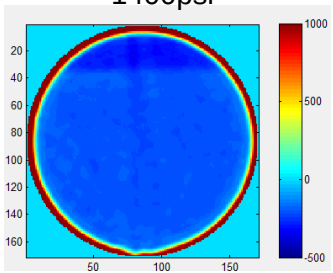
1000psi



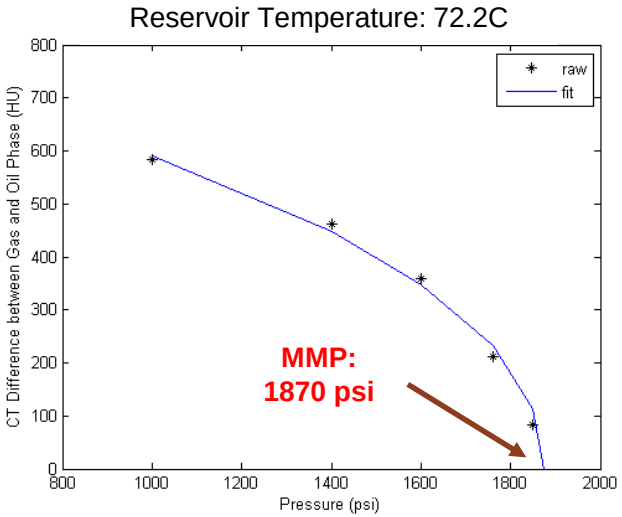
1400psi



1750psi

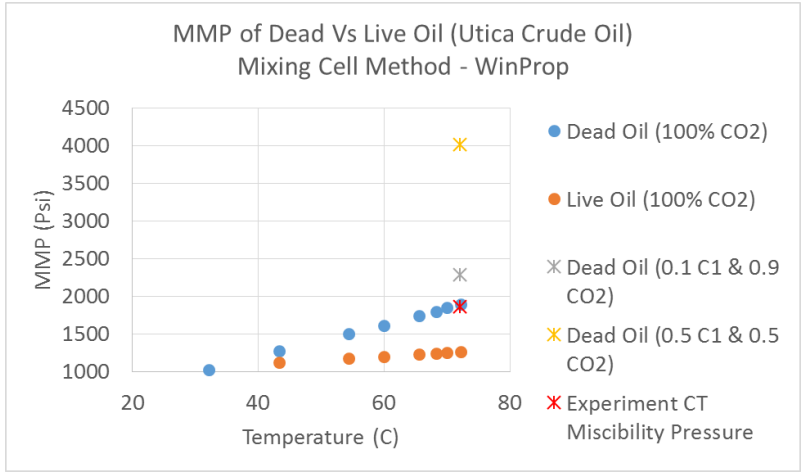


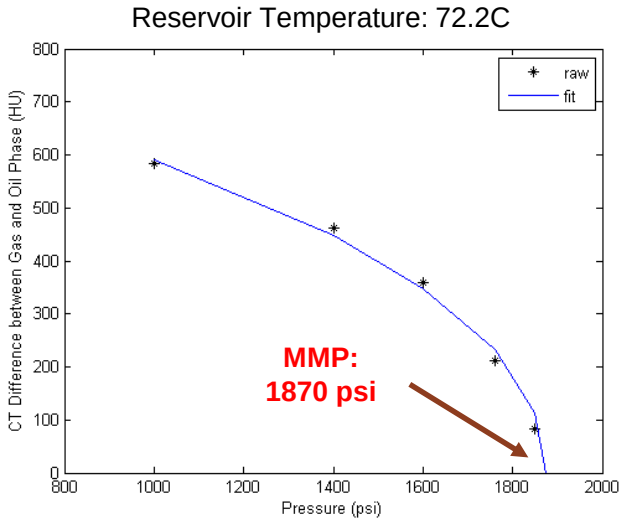
1850psi



Current Work – Part II

- Assessing CO2 Recovery
  - Saturating nano-Darcy core with oil
    - Setup pressure limit → maximize injectivity
    - Miscibility pressure of oil/CO2 → eliminating capillary pressure



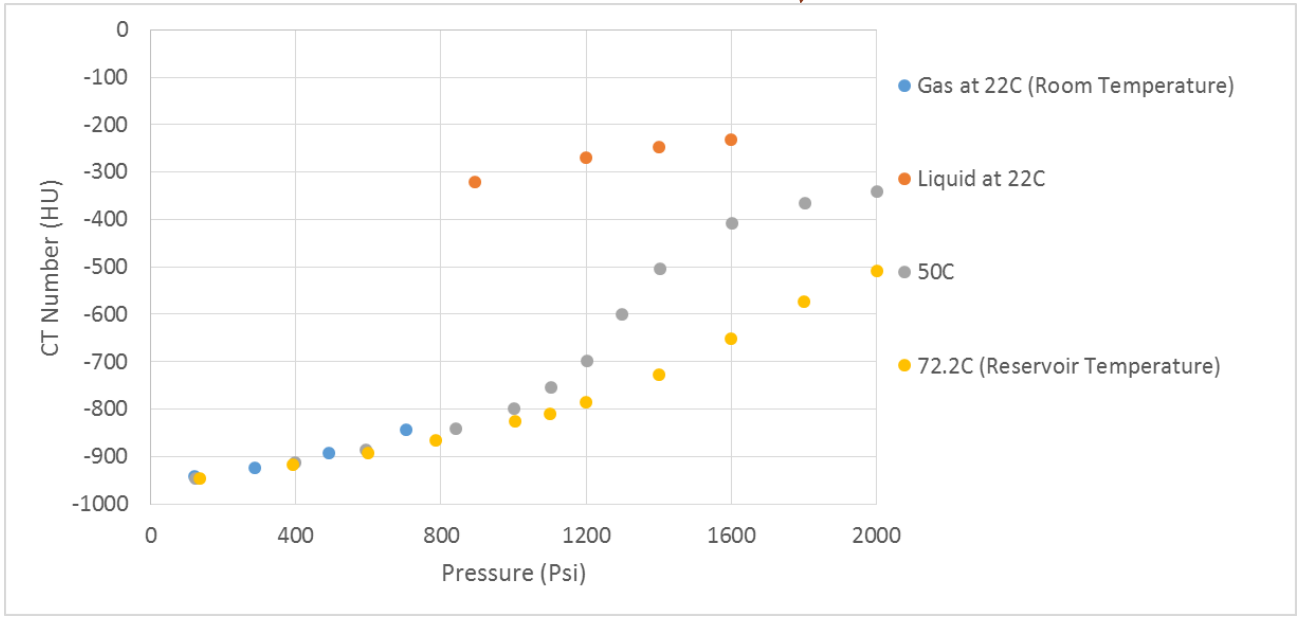


Current Work – Part II

- Assessing CO2 Recovery
  - Saturating nano-Darcy core with oil
    - Setup pressure limit → maximize injectivity
    - Miscibility pressure of oil/CO2 → eliminating capillary pressure
  - Measuring initial oil saturation
    - Mass balance (small volumes → large error)
    - CT method

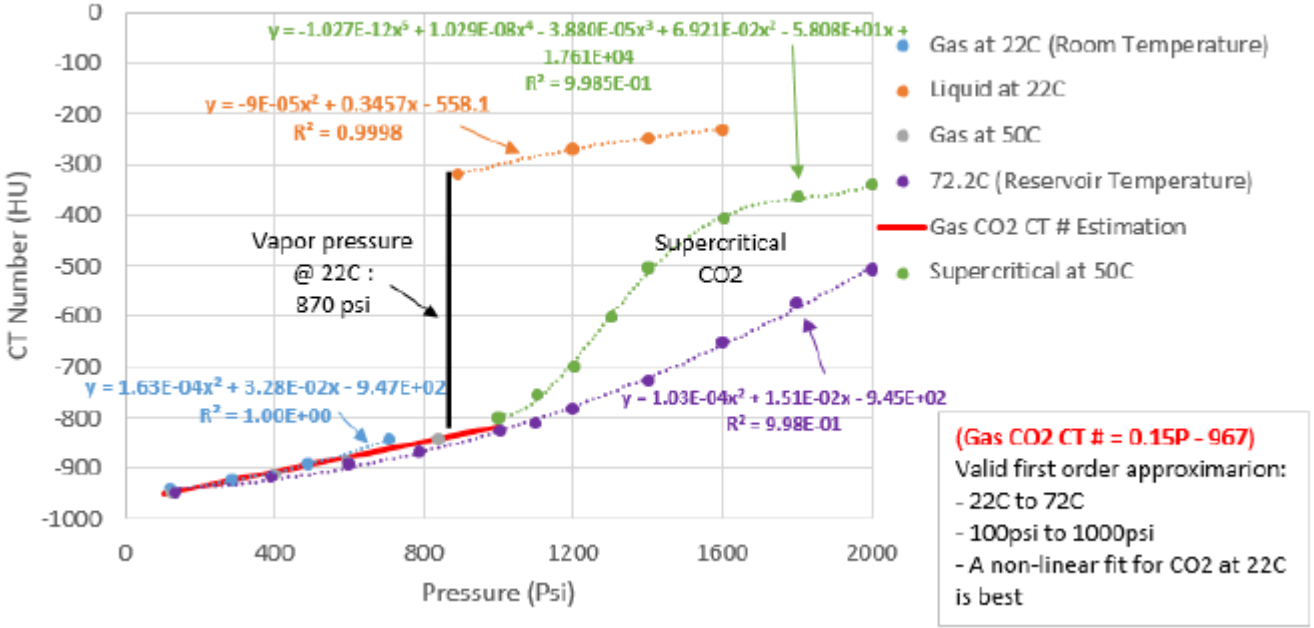
Initial Oil Saturation – CT Method

$$S_{o_i} = Avg\left(\frac{CT_{R-oil(2000psi)} - CT_{R-CO2\,(x)}}{\emptyset_{He}(CT_{oil\,(2000psi)} - CT_{CO2\,(x)})}\right)$$



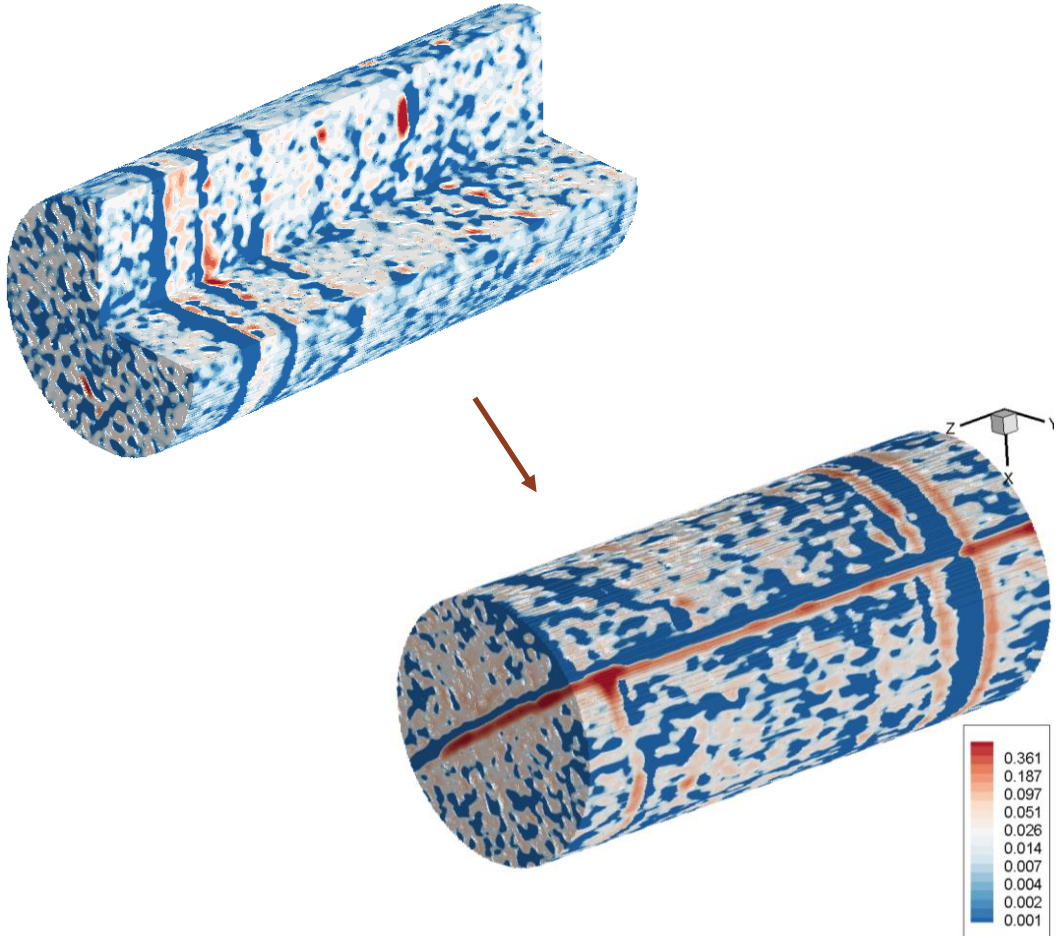
Initial Oil Saturation – CT Method

$$S_{o_i} = Avg\left(\frac{CT_{R-oil(2000psi)} - CT_{R-CO2\,(x)}}{\emptyset_{He}(CT_{oil\,(2000psi)} - CT_{CO2\,(x)})}\right)$$



Outline

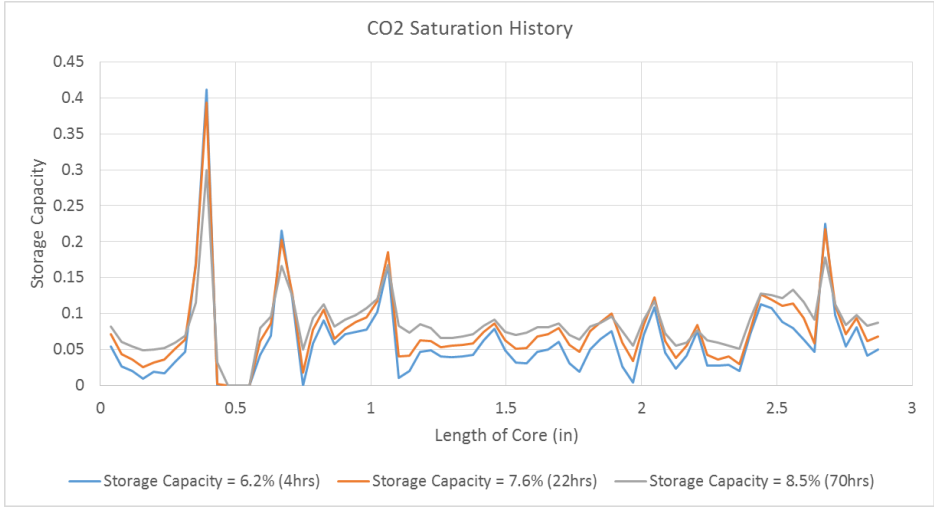
- Problem Introduction
- Objectives and Results
- Current Work
- Future Work



Future Work – (Linear Vs Triaxial) And (Huff n Puff Vs Continuous)

Tasks:

1. Run pulse decay for CO2 (pre-saturation phase)
2. Investigate 2 liquid/gas phase influence on oil recovery (50C vs 72C)
3. Match fracture systems results using direct input of 3D CT images into STARS with minimal upscaling
4. Expand to field scale simulation (E300)



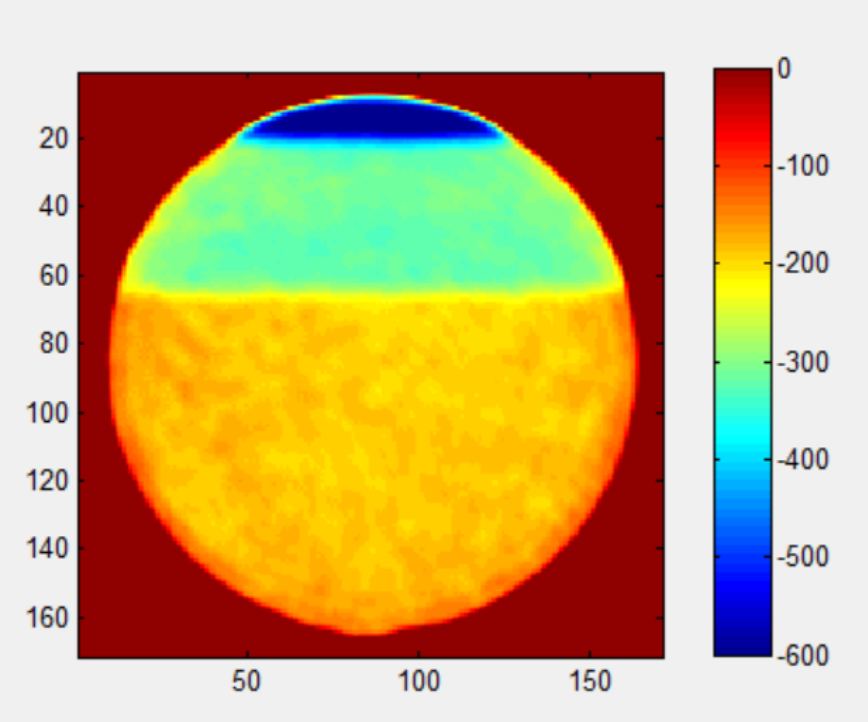
Linear Fractured Sample (NES: 500psi)
Helium: **5.8%**
CO2: **8.5%** (~70hrs @ 1200Pp)

Future Work – (Linear Vs Triaxial) And (Huff n Puff Vs Continuous)

SUPRI-A Stanford University

Tasks:

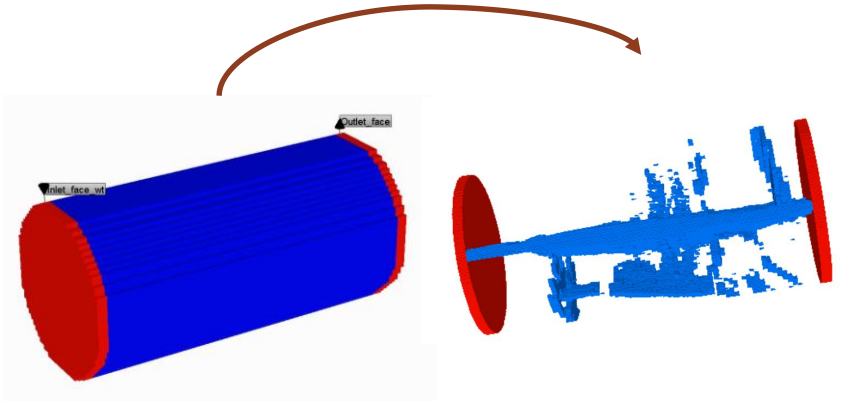
1. Run pulse decay for CO2 (pre-saturation phase)
2. Investigate 2 liquid/gas phase influence on oil recovery (50C vs 72C)
3. Match fracture systems results using direct input of 3D CT images into STARS with minimal upscaling
4. Expand to field scale simulation (E300)



Temp: 52 C
P: 1150 psi

Future Work – (Linear Vs Triaxial) And (Huff n Puff Vs Continuous)

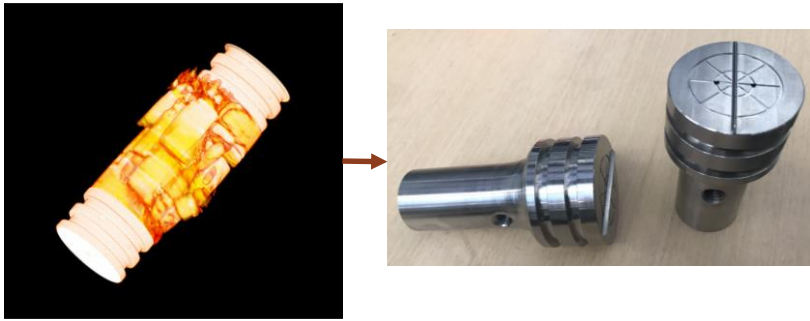
Fracture Geometry Import into CMG



Tasks:

1. Run pulse decay for CO2 (pre-saturation phase)
2. Investigate 2 liquid/gas phase influence on oil recovery (50C vs 72C)
3. Match fracture systems results using direct input of 3D CT images into STARS with minimal upscaling
4. Expand to field scale simulation (E300)

Complex Geometry

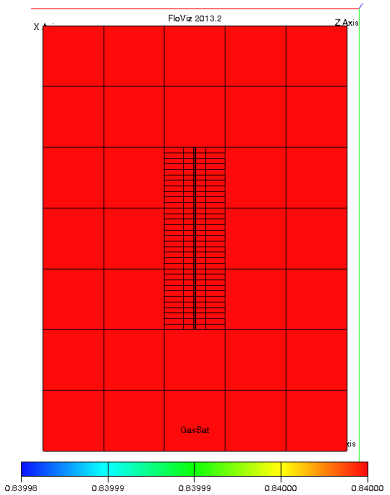


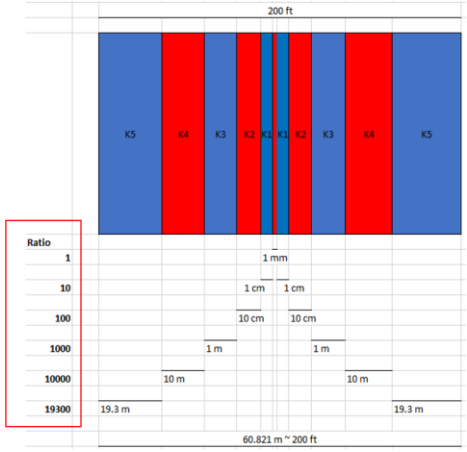
Courtesy of Guenther Glatz

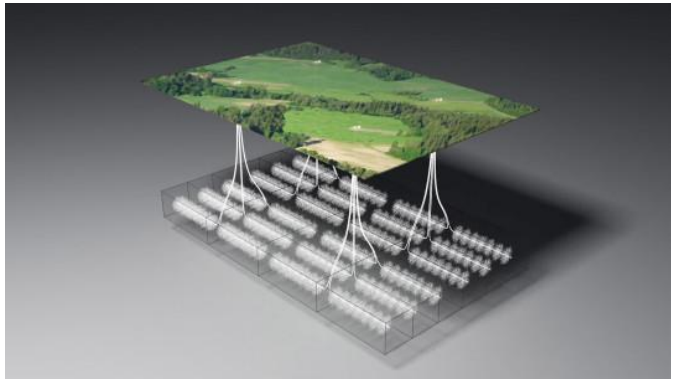
Future Work – E300 Field Model

Tasks:

1. Run pulse decay for CO2 (pre-saturation phase)
2. Investigate 2 liquid/gas phase influence on oil recovery (50C vs 72C)
3. Match fracture systems observations using grid refinement for linear fracture cores and direct input of 3D CT images into STARS in complex triaxial induced fracture systems
4. Expand to field scale simulation (E300)







Acknowledgement

- Tony
- Elliot, Guenther, Beibei, and Markus
- Supri-A Group
- Supri-A Affiliates

Acknowledgement

- Tony
- Elliot, Guenther, Beibei, and Markus
- Supri-A Group
- Supri-A and SCCS Affiliates

Thank You!