A Brief History of CO$_2$ EOR, New Developments and Reservoir Technologies for CO$_2$ EOR in Conjunction with Carbon Capture, Utilization and Storage (CCUS)

Presented at the 26$^{th}$ Annual CO$_2$ Conference
Tuesday - Thursday Dec 8$^{th}$-10$^{th}$, 2020

Bush Convention Center
Midland, Texas
Carbon dioxide flooding (CO₂ Enhanced Oil Recovery or CO₂ EOR) was developed 40 years ago as a method to produce higher percentages of the oil that resides in a reservoir. It has grown into a sub-industry producing almost 300,000 barrels a day from over 180 enhanced oil recovery (EOR) projects around the world. During the life of a project, almost the entire amount of CO₂ purchased for the project remains stored in the reservoir while an amount roughly equal to that purchased volume of CO₂ project remains stored in the reservoir while an amount roughly equal to that purchased volume of CO₂ is recycled and reinjected in what is commonly called a “closed loop system.” Given some form of incentives for CO₂ storage like the 45Q tax credit in the U.S., the economics of CO₂ EOR change and can greatly expand CO₂ capture projects and CO₂ EOR deployment. With the concurrent CO₂ storage (often referred to as Carbon Capture Utilization and Storage or CCUS), the EOR projects produce a lower carbon oil than other oil utilized today and will open up new targets called residual oil zones (ROZs) which can be thought of as hybrid deep saline reservoirs with the capability to produce some lower carbon oil to offset costs of industrial CO₂ capture projects.

Research related to the ROZs along with the explosive growth of horizontal drilling are beginning to be seen as adding greatly to reservoir understanding. All horizontal drilling requires depressuring of the producing formations while producing small amounts of the oil in place. The depressured pore space can be followed by CO₂ injection to further enable CO₂ EOR and CCUS while producing a greater portion of the stranded oil resource. It also can offset the expense and accelerate the capture of surface-sourced carbon dioxide and permanently storing the CO₂ in large volumes in reservoirs and out of the atmosphere.
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Outline of Presentation

I. A Brief History of CO$_2$ Enhanced Oil Recovery
   II. The Mounting Competition to Advanced Recovery
   III. New Developments
       A. Well Drilling and Completion
       B. Reservoir Understandings
   IV. CO$_2$ Emissions Capture and Storage
The History of CO₂ EOR

1960’s    A Couple of Small Scale Pilot CO₂ Injection Projects Were Implemented
1972     CO₂ Capture & Compression was Installed in the Southern Permian Basin at Val Verde Nat’l Gas Plants, PLs Built to McCamey and Snyder for the SACROC and North Cross Fields, First Large Scale CO₂ EOR Projects Begun
1978-79 Cortez, Bravo Dome and Sheep Mtn PLs Planned and ROW Acquired
1982    Pipelines Completed and Large San Andres Oilfields Began Injecting
1980s   CO₂ PLs and EOR Projects Started in Rockies, Gulf Coast, Michigan, Canada, Hungary, Turkey, Romania and Trinidad

Late 70s to 2014 Continued Growth in the Permian Basin, Mississippi, and Rockies
2000’s CO₂ Supply Limitations in the U.S. – Slowing of New Projects & Project Expansions
2018    New Projects on Hold Due to Low Oil Prices
Graphical History of CO₂ EOR*

The Phases of CO₂ Enhanced Oil Recovery*

Note the “Cyclicity”

CO₂ Pricing Began to Tie to Oil Prices

"New Day"?

Perennial Basin History of CO₂ EOR Project Starts and Cumulative Project Starts

* as Benchmarked to the Permian Basin Region of the SW U.S.
The Permian Basin and Worldwide Project History

GROWTH OF WW, U.S. and PERMIAN BASIN CO₂ EOR PROJECTS
1992 - 2018

- Worldwide Projects
- U.S. Projects
- Permian Basin Projects

YEAR
NO. OF PROJECTS
0 20 40 60 80 100 120 140 160 180

Melzer CO₂ Consulting
The Permian Basin and Worldwide Production History

WW, U.S., & PB CO₂ EOR PRODUCTION
1986 - 2018

YEAR

CO₂ EOR PRODUCTION - kbopd

Worldwide  U.S.  Permian Basin

U.S. = 300,000 bopd
PB = 200,000 bopd

* Ref: O&GJ Biennial EOR Editions & UTPB Petr Industry Alliance
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Despite the “2020 Double Whammy*”, Much of Our Oil & Gas Industry is Still Feeling the Excitement

• Producing Unconventional Reservoirs
• Producing Unconventional Oil (More on this Later)
• The Explosion of Innovative Tools for Horizontal Completions
• Better Drilling Rigs and Bits for Faster Drilling

* The Saudi ‘Flotilla’ of Tankers (Feb 2020) and Covid-19 Oil Demand Destruction
Where is CO$_2$ EOR in all this New Excitement? (1)

- The ‘Turtle and the Hare’
  - CO$_2$ EOR is the Turtle
    - Steady but Slow Growth
Where is CO\textsubscript{2} EOR in all this New Excitement? (2)

- The ‘Turtle and the Hare’
  - CO\textsubscript{2} EOR is the Turtle
    - Steady but Slow Growth
Where is CO$_2$ EOR in all this New Excitement?

- The ‘Turtle and the Hare’
  - CO$_2$ EOR is the Turtle
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- IRR vs. Booking Reserves
  - Short Term Payouts vs.
  - Long Term Perspective?
Then Compare Undisc Cash Flow of the Reservoir Depressuring Wells to the CO₂ EOR Project

- Horizontal Drilling Project Setup is Easier, Can Start Earlier

Conclusion: Less 'Out-of-Pocket' Cash and Faster Payout but Makes Less Oil, Lasts only 10 Yrs
So Where is CO₂ EOR in all this New Excitement? (4)

• The ‘Turtle and the Hare’
  o CO₂ EOR is the Turtle
    o Steady but Slow Growth

• IRR vs. Booking Reserves
  o Short Term Payouts vs.
  o Long Term Perspective?

• Looking at a “Second Life?”
  o CCUS (Concurrent Oil Production and CO₂ Storage)

45Q – Value of Credit

Two different values are available:

1. EOR TYPE
   • Must be used as a tertiary injectant in enhanced oil recovery (EOR) or natural gas recovery project (or “utilized”)
   • Must be disposed of in “secure geological storage” (or “utilized”)
   • Old value per metric ton: $10 (2009), adjusted for inflation annually
   • New value per metric ton: $12.83 (2017) up to $35 (2026)

2. NON-EOR TYPE
   • Cannot be used as a tertiary injectant or “utilized”
   • Must be disposed of in “secure geological storage”
   • Old value per metric ton: $20 (2009), adjusted for inflation annually
   • New value per metric ton: $22.66 (2017) up to $50 (2026)

= $2.00/Mcf
= $2.60/Mcf
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Let’s Look Closer at the New Learnings that have Come from the Horizontal Revolution and CO₂ EOR

Several, Incidentally, come from the San Andres ROZ Studies (Originally Motivated by our CO₂ EOR Interests)
Very Quickly: What is a Residual Oil Zone?

- It is an Interval in a Formation with Immobile Oil but the Moveable Fluid is Water
- It can be Formed by Man’s Waterfloods or by Nature
- In the Geological Past it was a Paleo Oil Entrapment and Subsequently Invaded by Water
- There are Three General Types of Natural ROZs based upon how the Water Invaded the Paleo Trap
- The One Most Common and Extensive is a Laterally Swept ROZ

ROZs can underlie an oil field and can also be present with no main payzone above (“Greenfield”)

Type 3 ROZ (Laterally Swept)
Summary of Recent (Key) New Learnings (1)

1. We already Mentioned the Faster Drilling and Completion Tool Innovations (....and there are many!)

2. Horizontal Wells are Demonstrating Vertical Transmissive Fractures are More Common than Believed in the Age of Vertical Wells

3. Flowfields in Transmissive Fractures are Often Present and Generally Analogous to ROZ Flowfields Causing Sour Oil and Gases Even in Normally Sweet Oil Environments

4. Intrinsic Microbes Alter the Oils, Gasses, and Even the Rocks But Their Effects are Relatively Minor without Flowfields to Disseminate the Normally Inhibiting H₂S (More on this later)
Summary of Recent (Key) New Learnings (2)

5. Residual Oil Zones (ROZs) are Common in Many Basins and Should be Recognized as Different from Transition Zones
6. ROZs can be Found Beneath the OWCs and in ‘Greenfields’
7. ROZs can be Commercially Exploited with (CO$_2$) EOR
8. Gassy ROZs can be Commercially Exploited with Horizontal Well Primary Recovery (Reservoir Depressuring)
9. Limited Natural Waterflood Sweep Leaves Gassy ROZs
10. Unlimited Natural Waterflood Sweep Leaves a ‘Heavy’ Oil
11. New Studies are Suggesting Oil- and Mixed-Wettability in a Formation are Often Functions of the Oil & Water ‘Swap’ Process and Related Microbial Activity in a Reservoir
All But that Last New Learning Have Been Addressed in Past Annual CO$_2$ Conferences (*see CO2Conference.net*)

- Most of those Learnings had Their Origins from Enhanced Recovery Studies and Observations Related to ROZs
- Many Apply to the Horizontal Revolution
- Many Relate Directly to CO$_2$ Geological Storage and Relate to GhG Emission Reductions (Segues to the Last Section)
Let’s Examine that Aforementioned H$_2$S Generation

\[
\text{aq}) \text{SO}_4^{2-} + \text{CH}_4 \rightarrow \text{aq}) \text{CO}_3^{2-} + \text{H}_2\text{O} + \text{H}_2\text{S}
\]

- S is +6
- C is -4
- C is +4
- S is -2

Microbes remove 8 Electrons from the Carbon and transfer them to the Sulfur

the Source Sulfate is Reduced and is Released as H$_2$S to Sour the Oil and Gas

Re: Vance, David (2012), RPSEA II Project Chapter 4 (adapted)

Note: This Process is Active When H$_2$S Concentrations Remain Low, i.e., < 200 ppm)
Now Taking the ROZ Biogeochemistry Insights One Level Further

• First, Why Hasn’t the Industry Noted this Before?
  • Accumulations of $H_2S$ from the Aforementioned Process Inhibits Continued Microbial Activity: Minimizing the Microbial Effects
  • The Lateral Sweep ROZ and its Flow Field Disseminates the $H_2S$: Amplifies the Process and Effects Such that Observational Enigmas* Emerge

* In the San Andres Fm of the PB, we see 300’ Thick Oil Shows Below the Oil/Water Contacts, 300’ Thick Oil Shows without an Overlying Main Payzone, Nearly Uniform 30-40% Residual Oil Saturations for 300’ Distances Below the OWC, etc. In most other formations and in other basin, those shows are thinner and we dismissed as transition zones
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• What About the Shorter-lived Flow Field In the Original Oil Entrapment?

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This also leads Us to Talk About Wettability

Honapour, M et al (2012), SPE 133089 – Fig 14
The Dominant Dolomization Process
(At Least for the San Andres Formation)
Key Biogenic (Redox) Reaction

\[(\text{aq}) \text{CaSO}_4 + \text{CH}_4 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} + \text{H}_2\text{S}\]

- S is +6
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- Microbes remove 8 Electrons from the Carbon and transfer them to the Sulfur

- \(\text{H}_2\text{S} \) is Created and Can Inhibit Future Activity (But...A Flowfield Can Disperse)

- Dolomitization Typically Follows as Well
  \[\text{CaCO}_3 + \text{Mg} \rightarrow \text{MgCa(CO}_3\text{)}_2\]

We are showing Methane here as the source of carbon but.....it may be other hydrocarbons molecules also

Will also Create Saturated \(\text{SO}_4\) Conditions in the Water

Souring the Oil and Gas

New Dolomite Surfaces Attract Oil over Water, Re: Oil Wettability

Re: Vance, David (2012), RPSEA II Project Chapter 4
If the matrix, clastic particles, or cement is carbonate or arkosic, the rock will have a preference to oil over water and, (our theory) when during the original oil entrapment and water/oil exchange occurs, some mixed wettability will result.
I Need to Stop Here for a Minute and Give Due Credit to Two Persons on our ROZ Team

• Dr. Robert Trentham at UTPB (Trentham_r@utpb.edu); For his insights on the Permian Basin tectonic history and his wealth of general geological expertise

• David Vance at Arcadis (David.Vance@arcadis.com): for his invaluable scientific understanding of biogeochemistry, intrinsic microbes present in the earth, and the biological processes often at work in anaerobic environments
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Greenhouse Gas (GhG) Emissions Capture

- The Clean Air Act (CAA) of 1970 gave EPA the Authority to Establish National Ambient Air Quality Standards (NAAQS) to Control Emissions – Particulates, $S_{ox}$, $NO_x$, and others

- In 2007 the US Supreme Court Classified Heat Trapping Emissions (including Both Methane and $CO_2$) as “Air Pollutants” and (under the CAA) the U.S. EPA was Given Authority to Pass Regulations to Curb GhG Emissions
  
  - They became Included in New Source Performance Standards (NSPS) and Required Emissions to be Reportable at Plants/Projects Exceeding Certain Threshold Emissions
  
  - The New Classification also placed GhGs into Regulatory Control under EPA’s Federal Safe Drinking Water Act (SDWA {1974})

* The “U” Representing Utilization Like in $CO_2$ EOR where the $CO_2$ is Injected for Producing Oil but also Storing $CO_2$ in the Reservoir
No Other Utilization Scheme has Yet to Show it can Abate CO₂ Emission Streams to the Levels that CO₂ EOR can Handle

• The Permian Basin Alone has Already Securely Stored over 20 Trillion Cubic feet (1 billion metric tons)
• There is Pore Space in Many Basins Around the World also that are Available if Given Capacity to Deliver the CO₂ There can be Implemented
• The Formation Depressuring Occurring with the Shale Plays is Greatly Adding to the Pore Space that is Available
• The CCUS Technology is Proven and Ready to Go to Work on CO₂ Emission Reductions
Thank you

Time for Questions?
Backup Slides
San Andres ROZ Horizontals
Cumulative Oil & Gas

Horizontal San Andres ROZ Play Cumulatives

- Cum Oil - KBO
- Cum Gas - MMcf
- # of Producing Wells (Rt Scale)

Cumulative Oil & Gas - KBO and MMcf

# of Producing Wells

Mo-Yr

Jan-12 Jan-13 Jan-14 Jan-15 Jan-16 Jan-17 Jan-18 Jan-19 Jan-20
Modelling Results of a One-square Mile San Andres Fm Residual Oil Zone Area

• CO₂ EOR
  • 16 Producers, 9 CO₂ Injectors

• Horizontal Depressuring
  • 7 Total One-mile Long Laterals

• CO₂ EOR
  • Produces 5.8 million Bbls in 10 Years and 9.8 Million in 25 Years
  • Stores Over 70 Bcf (>4 mm tons) of CO₂
    • Payout of 5 Yrs Reduced to 3.5 Yrs w/ ½ Price CO₂, >300% ROI in 9 Yrs

• Horizontal Depressuring
  • Produces 1.6 million Bbls until Uneconomic (~10 years)
    • Payout in 2 years, 100% ROI 10 Yrs
We Had a New Discovery Here in the PB

What would you call this zone?

Note: 400' !!!

Anhydrite Cap

Oil Saturation - %
Key Biogenic (Redox) Reaction

\[
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Souring the Oil and Gas

New Dolomite Surfaces Attract Oil over Water, Re: Oil Wettability

Re: Vance, David (2012), RPSEA II Project Chapter 4
One Might Call this Learning #12

Sulfate, Unlike Carbonate, is

- Less Soluble When the Water is Cooled
- Production Data Shows JT Effect has Created some Flow Constrictions
- Sulfate Inhibition Chemical (applied at the Flush Stage) of Fracture Treatments is Used Successfully
- Can Require Treatments of Laterals to Convert Sulfate to Carbonate and Acidizing