CO₂ Enhanced Oil Recovery (EOR) Basics, Definitions and Performance Concepts

Let’s Call it “CO₂ EOR Blitz – 101”

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Outline of Talk (1)

I. Production Stages: Primary, Secondary, Tertiary

II. EOR and Types of “Flooding”

III. Flooding Geometries (Pattern, Vertical, etc)

IV. Reservoir vs. Surface Conditions

V. Where is CO$_2$ EOR Done? How Big is the Market?

VI. Gaseous and ‘Dense’ (aka Supercritical) States
Outline of Talk (Cont’d)

VIII. Efficiency Terms
   – Reservoir Sweep Efficiency
   – CO₂ Utilization Factors (how much CO₂ to get a bbl of oil?)

VIII. Chief Contributing Factors to Flood Inefficiency

IX. CO₂ Storage

X. Other Terms/Rules of Thumb/Growing Capture and Storage

XI. Questions?
Oil Recovery

- **Primary:** Utilizes Natural Pressure in the Formation (Fm) to Move Fluids to the Borehole
- **Secondary:** Some Producing Wells are Converted to Injection to Repressure Fm and Push Oil to Remaining Producers; **Cheap is Good** so **Water** is Most often the Choice Injectant
- **Tertiary:** Switches to an Injectant that Mixes with the Oil to Change its Properties and Mobility within the Reservoir (Water Does Not Mix with Oil)
Classical Phases of Oil Production Vs. Time

Primary Stage

Secondary Stage
Typically Water Flooding

EOR

~10% ~20% ~15-20%

Oil Recovered (bbls)

Recovery % of Original Oil in Place

EOR (Incremental) Oil
Types of Advanced Oil Recovery

- Water Floods (*light oils, all depths*)
- Enhanced Oil Recovery Methods
  - CO$_2$ Flooding (*light oils, intermediate depths*)
  - Steam Flooding (*heavy oils, shallow depths*)
  - Chemical Flooding (*niche applications*)
  - HC Miscible Gas (HCMF) Flooding (*where the NGLs are in excess supply*)
  - Nitrogen (*light oil, deep depths*)
  - Others

EOR
The Strange Properties of CO₂

- You know CO₂ as a by-product gas
- At ~1200 psi it changes state and become dense like a liquid (& close to crude oil’s density)
- It also has solvent properties and mixes with oil (“miscibility”)
- It will clean a rock of its oil – hence its use in EOR

Density of Water

Gas Density

Density of CO₂ for a range of pressures and temperatures. The density of water (1 gm/cm³) is 62.43 lbs/ft³.

From Stallcup, F.I., SPE Monograph entitled Miscible Displacement

Unfortunately out of print
Where is CO$_2$ EOR Done?
Where is CO₂ EOR Done?

Legend
CO₂ Sales
30 - Million Tons/Yr
How is it Done?
EOR and Flooding Geometries

- Pattern (Horizontal) Flooding

- Vertical (Gravity Assisted) Flooding

ROZ = Residual Oil Zone = the oil left behind after water passes (Sweeps through)
RESERVOIR SWEEP CONCEPTS

“It is not Always a Homogeneous Subsurface World”

• AREALLY SPEAKING

• VERTICALLY SPEAKING
RESERVOIR SWEEP CONCEPTS

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How Much CO₂ Does One Need to Produce a Barrel of Oil?

- Need to Think about “New” (Purchased) and “Recycled” CO₂ Rule of Thumb is that it is always cheaper to recycle CO₂ than to buy new

- We Use the Term “Utilization Factor” (UF) to Define How Much CO₂ it takes to Produce a Bbl of oil

   “Net” UF = New Mcf/Bbl; “Gross” UF = Total Mcf/Bbl (incls Recycle)

- Can Be Measured Instantaneously or Cumulatively
Example of CO₂ Purchases for a 15-Injection Well (Ph 1) followed by a 8-Injection Well (Ph 2) Project
How Much CO₂ is left in the Reservoir after a CO₂ EOR Project?

- Since the CO₂ Produced with the Oil is Recycled and the Project Wells are Plugged & Abandoned after the EOR Project, the only Losses to the Atmosphere are the Small Volumes that are Flared During a Plant Upset (e.g., Power Losses, Compression Outage)

- The Stored CO₂ is Commonly 95% or More of the Purchased CO₂*

- Storage is Effectively Permanent – i.e. When you quit pushing it “locks in”

* Reliability of the Power Provider is the Key Issue
Partial Review
Some Important CO$_2$ EOR Terminology

- Carbon Dioxide (CO$_2$): Generally Referring to the Substance at Pressure and a Purity >95%
- Supercritical State: Not Really a Gas nor a Liquid, Possesses Properties of Both
- Miscibility: A Condition of Mixing wherein CO$_2$ and Oil Mix to Form a New Combined Material
- Water Alternating Gas (WAG): The Process by Which Injected Fluids are Switched Back and Forth Between Water and CO$_2$
- CO$_2$ Utilization Factor (UF): How Much CO$_2$ is Needed to Produce a Bbl of Crude Oil – Measured in Purchased CO$_2$ (Net UF) and/or Total (Purchased + Recycled = Gross) CO$_2$
Some Handy Conversions

• 50 million cubic feet per day (mmcfpd) is roughly equal to 1 million tons per year (slightly less than 1 for metric tons {mt} and slightly more for english tons {ton})

• 17.5 mcf ~ 1 ton CO₂

• 19.25 mcf ~ 1 mt (tonne)

• For quick calculations (i.e., rule of thumb) in an efficient & mature CO₂ EOR project, we often use 3 bbls of crude oil produced by a mt of CO₂
Some Handy Rules of Thumb

• An Efficient CO\(_2\) Flood (a Good Sweep Efficiency) will need to have CO\(_2\) at a Pressure to be Miscible with the Oil. Miscibility is Achieved above the Critical (Dense) State (~1200 psi) which will Require the Reservoir to be Below 2500-3000’ Depth

• Trucked CO\(_2\) is Expensive – Pipelines are Needed

• The Distance to a CO\(_2\) Source can be a Huge Impediment for Economical Flood

• A Time-tested Formula for What an Oil Producer Can Afford to Pay for CO\(_2\) Delivered to his Project is 2% of the Oil Price where Oil is in $/Bbl and CO\(_2\) Price is in $/Mcf (@ $50/Bbl that is $1.00/Mcf or $19.25/metric ton)
Comments on the Scale of Opportunity

- CO₂ EOR has often been Portrayed as a ‘Niche’ Industry as it accounts for only 3% of U.S. Oil Produced
- It is not a Niche in Terms of Qualified Reservoirs
- The Largest Factors Limiting its Growth have been Distance to the Sources of CO₂ and Longer Project Payout Times
- An Incentive for the “Incidental” CO₂ Storage Occurring During an EOR Project Would Clearly Change the Dialogue* and Pace of Project Deployment

* Like the 45Q Bill Proposes or like the LCFS or Emission Trading Credits
Resources for Further Study

  Fred Stallcup’s SPE Monograph; Paul Willhite & Marty Dubois (also great resources)

• US DOE’s Primer on CO₂ EOR (includes CCS) [https://www.netl.doe.gov/file%20library/research/oil-gas/small_CO2_EOR_Primer.pdf](https://www.netl.doe.gov/file%20library/research/oil-gas/small_CO2_EOR_Primer.pdf)

• Diving in a bit Deeper?: Practical Aspects of CO₂ EOR (SPE Monograph) and [www.CO2Conference.net](http://www.CO2Conference.net)
Time for Questions?

….and a Plug for the 23rd Annual CCUS & CO₂ Conference

December 4-7, 2017

For More Information go to www.CO2Conference.net