Measurements and Methods in CCS & EOR

By: Zhang Xiansong

CNOOC Research Institute
China National Key Lab of Offshore Oil Exploitation

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Outline

1. CCS overview

2. Integrating CO2-EOR and CO2 Storage
   - CO2-EOR
   - Improved methods

3. Application & Prospect
   - Case
   - Prospect

4. Summary & Suggestions
What is CCS?

• Carbon Capture and Storage (or Sequestration) is a broad term for technologies involving three main steps:
  - capturing the CO2 from the combustion of fossil fuels at stationary sources
  - transporting it to the storage site and
  - storing it underground in geological formations.
CCS Overview

- **Capture**
  - Power plants
  - NG treatment
  - Oil refineries

- **Transportation**
  - Pipelines
  - Ships

- **Sequestration**
  - Geological formations (underground)
  - Ocean
CCS Overview

○ Systems
  ○ Post-combustion
  ○ Pre-combustion
  ○ Oxy-fuel
  ○ Industrial processes (e.g. NG sweetening)

○ Separation technologies
  ○ Solvents – aqueous amines and salts
  ○ Membranes – polymeric
  ○ Solid sorbents – Lime, zeolite, activated carbon
  ○ Cryogenic processes – Liquefaction/distillation
## Carbon Sequestration

### Comparison of CO₂ geological storage methods

<table>
<thead>
<tr>
<th>Storage Methods</th>
<th>Advantages</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOR in Oil fields</td>
<td>Mature technology, Extra economic return, Safe</td>
<td>Complex process; Gas injection volume and position limit; Safety of abandoned wells in oil field; Leak in fracture in the oil field.</td>
</tr>
<tr>
<td>EGR in Gas fields</td>
<td>Extra economic return; Large storage capacity. Safe.</td>
<td>Complex process; Lack of experience; Gas mixing and separation costs; Safety of the original wells.</td>
</tr>
<tr>
<td><strong>EGR in Coal bed gas fields</strong></td>
<td>Enhanced CH4 recovery, Near to CO2 resource (Power Plant).</td>
<td>Complex process; Low CO2 injection ability; Gas mixing and separation costs; Lack of experience</td>
</tr>
<tr>
<td><strong>Storage in deep aquifer</strong></td>
<td>Simple operating process; Large storage capacity.</td>
<td>No economic return; Long term security not confirmed; Lack of experience</td>
</tr>
</tbody>
</table>

**Storage Methods**
- EOR in Oil fields
- EGR in Gas fields
- EGR in Coal bed gas fields
- Storage in deep aquifer
Overview of the CO2 Geological Sequestration System

- Capture
- Transportation
- Injection

Injection from onshore Facilities
Capture
Injection from offshore Facilities

Pipeline Transportation
Large-Scale CO2 Emission Source
Pipeline Transportation

Cap Rock
CO2
Onshore Aquifer
CO2
Offshore Aquifer
Carbon Sequestration

- Big Storage in oil reservoirs (depleted and EOR), natural formations, ocean storage
- Will it leak? Not likely – models suggest 99% containment
- Existing reservoir data can be used to estimate storage potential and address (water) concerns
- No groundwater contamination (salt?)
Integrating CO2-EOR and CO2 Storage Could Increase Storage Potential
**Benefits Of CO\textsubscript{2} -EOR**

**CO\textsubscript{2} Flood**

Proven EOR process

Recover additional 15%– 25% IOIP

Extend production life by over 15 – 20 years

Reduce emissions of CO\textsubscript{2}
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Schematic of CO2-EOR Injection

Graphic representation of CO$_2$ injection in reservoir for enhanced oil recovery (EOR)
Types of CO2-EOR

- Miscible CO₂ Flooding (MMP)
- Immiscible CO₂ Flooding
- Immiscible CO₂ Huff & Puff
Reservoir conditions of CO2-EOR Projects (USA)

CO2-EOR prefer: sandstone, limestone, dolomite reservoirs with low perm. light oil, etc.
The depth of most CO₂ Projects were among 1000～3000, most CO₂ miscible Projects were used in reservoirs with oil API > 30, most immiscible projects used in shallow reservoirs (<2000m), and higher API (< 30).
Recovery Mechanisms Of CO₂ Flood

- Oil viscosity reduction
- Oil swelling
- Vaporization of oil (CO₂ extraction)
- Interfacial tension reduction
- Miscibility effects
What Should CO\textsubscript{2} EOR be Focus on?

Feasibility research of CO\textsubscript{2}-EOR Projects

- Displacement mode
  - Experiments
    - CO\textsubscript{2}-Oil PVT
    - MMP
  - Reservoir Simulation
    - Basic Parameters
What Should CO₂ EOR be Focus on?

- Minimum miscibility pressure (MMP)
- Impurity in CO₂
- CO₂ injection strategy
- Wettability change and acidic effect
- Water blocking of oil
- Viscous instabilities, gravity segregation
- Heterogeneity
Improve the CO2-EOR injection pattern

CO2 flooding front early breakthrough
Improve the CO2-EOR injection pattern

water & gas injection alternately
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Survey of CO2 EOR technologies application

Most CO2—EOR Projects are in North America;
CO2 Projects in USA are mainly Miscible;
Most projects (61, 74% of total) are carried out after water flooding;
Recovery increased by about 8~15%.

Field application analysis:

<table>
<thead>
<tr>
<th></th>
<th>Successful</th>
<th>Hopeful</th>
<th>Too early</th>
<th>Failed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>56</td>
<td>16</td>
<td>5</td>
<td>5</td>
<td>82</td>
</tr>
<tr>
<td>Percent</td>
<td>68%</td>
<td>20%</td>
<td>6%</td>
<td>6%</td>
<td>100%</td>
</tr>
</tbody>
</table>
—CO2 from the United States by pipeline of 325 km to the oil field, over 5000 tons of CO2 daily (95% of CO2, the input pressure 18 Mpa)
—All produced CO2 i reinjection, accounting for 33% of the daily dosage
Case 1:

After injection CO₂ 25 years, EOR 13-19%
CO2-EOR Pilot in Daqing Oilfield

Case 2:

**Time:** From 1990 to 1995, two pilots of immiscible CO2 in different layers.

**Developing Mode:** Early-stage water flooding, Water alternative CO2 injection.

**CO2 injected volume 0.2PV.**

**CO2 source:** By-Product of Daqing oil refinery, purity 96%.

**Performance:** Recovery increased by 6%,
Reservoir viscosity: 0.681–0.817 mPa·s
Ground Density: 0.83～0.85 g/cm³
GOR: 20～50 m³/m³
Reservoir T: 108～110°C
Reservoir pressure: 21～23 MPa
Saturation pressure <15.96 MPa
Recovery 13.2%

CO₂ MMP: about 20–22 MPa
Present reservoir pressure 10.45 MPa

A17b well W3III ZoneC1 Sand: Area 0.8 Km², Reserves $44.9 \times 10^4$ m³.
The CO₂ storage is about $23.3 \times 10^4$ t in target field (OOIP $44.89 \times 10^4$ t).

According to above calculation result, the WZ12-1 field (with OOIP $2425 \times 10^4$ t and 7.4 Km²) has CO₂ storage capacity of $1258.7 \times 10^4$ t.

**Research of CNOOC**

**Estimation of CO₂ before breakthrough:**

$$M_{CO₂} = \rho_{CO₂res} \bullet R_{FBT} \bullet OOIP/\text{Sh}$$

Reservoir Density of CO₂

Recovery before breakthrough

OOIP

Oil Compression ratio

Shaw, 2002
Announced Projects

- There are many CCS projects being announced worldwide. This database also contains dormant projects; those which have had no news on for multiple years but which have not been publicly cancelled.
## Announced Projects

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Location</th>
<th>Leader</th>
<th>Size</th>
<th>Further information</th>
</tr>
</thead>
<tbody>
<tr>
<td>CarbonNet</td>
<td>Australia</td>
<td>Victorian Government</td>
<td>Network</td>
<td>2.5 Mt/yr</td>
</tr>
<tr>
<td>South West Hub</td>
<td>Australia</td>
<td>Western Australian Dep. Mines and Petroleum</td>
<td>2.5 Mt/yr</td>
<td>CO2 capture from various industrial sources, including fertilizer and power generation for onshore EOR.</td>
</tr>
<tr>
<td>Lula</td>
<td>Brazil</td>
<td>Petrobras</td>
<td>0.7 Mt/Yr</td>
<td>Capture and Sequestration EOR in offshore Lula oil field</td>
</tr>
<tr>
<td>Shand</td>
<td>Canada</td>
<td>SaskPower &amp; Hitachi</td>
<td>Unknown</td>
<td>SaskPower &amp; Hitachi to build CCS test facility</td>
</tr>
<tr>
<td>Shanxi</td>
<td>China</td>
<td>Shanxi Energy Group</td>
<td>350 MW</td>
<td>New build Super critical Power plant with 2-3 Mt/yr</td>
</tr>
<tr>
<td>Qilu Petrochemical CCS</td>
<td>China</td>
<td>Sinopec</td>
<td>0.5 Mt/yr</td>
<td>The FEED study has been completed and is awaiting approval by Sinopec. Anticipated start date is 2016. CO2 is to be used for EOR.</td>
</tr>
<tr>
<td>YiHe Coal plant</td>
<td>China</td>
<td>China Energy &amp; Seamwell</td>
<td>1000 MW</td>
<td>$1.5 billion clean coal plant to be built in Inner Mongolia (June 2011)</td>
</tr>
<tr>
<td>Ledvice</td>
<td>Czech Republic</td>
<td>CEZ</td>
<td>660 MW</td>
<td>Retrofit post combustion plant. Financing proposed</td>
</tr>
<tr>
<td>Hodonin</td>
<td>Czech Republic</td>
<td>CEZ</td>
<td>660 MW</td>
<td>Considering 2 sites for pilot plants</td>
</tr>
<tr>
<td>Hassyan Clean Coal</td>
<td>Dubai</td>
<td>DEWA</td>
<td>1200 MW</td>
<td>Dubai Electricity and Water Authority (DEWA) has competition to select developer for 49% of its new clean coal power plant. Commissioned by 2020</td>
</tr>
<tr>
<td>Nord</td>
<td>France</td>
<td>Total</td>
<td>N/A</td>
<td>The French Environment and Energy Management Agency (ADEME) selects the project for E54M</td>
</tr>
<tr>
<td>Saline Joinche Eemshaven</td>
<td>Italy</td>
<td>SEI</td>
<td>2*660 MW</td>
<td>EU announced CCS project [PDF]</td>
</tr>
<tr>
<td>RWE</td>
<td>Netherlands</td>
<td>RWE</td>
<td>0.19 Mt/yr</td>
<td>RWE project webpage</td>
</tr>
<tr>
<td>Husnes</td>
<td>Norway</td>
<td>Sargas</td>
<td>2.6 Mt/yr</td>
<td>Project webpage</td>
</tr>
<tr>
<td>Turceni</td>
<td>Romania</td>
<td>Turceni</td>
<td>1.5 Mt/yr</td>
<td>GCCSI awards Romania project $2.55 (October 2010)</td>
</tr>
<tr>
<td>Caledonia Clean Energy</td>
<td>UK</td>
<td>Summit Power</td>
<td>N/A</td>
<td>Project is on hold as more funding is secured for FEED and storage appraisal</td>
</tr>
<tr>
<td>Energy Project</td>
<td></td>
<td></td>
<td></td>
<td>Summit Power, National Grid and Petrofac Team Up on DECC Carbon-Capture Programme in UK (March 2010)</td>
</tr>
<tr>
<td>CO2 solutions and EERC</td>
<td>USA</td>
<td>CO2 Solutions and EERC</td>
<td>N/A</td>
<td>CO2 Solutions Announces Testing Program with Energy &amp; Environmental Research Center (EERC) (September 2014)</td>
</tr>
<tr>
<td>Medicine Bow</td>
<td>USA</td>
<td>Sinopec</td>
<td>2.5 Mt/yr</td>
<td>Medicine Bowl Project presentation (2011)</td>
</tr>
<tr>
<td>Quintana</td>
<td>USA</td>
<td>Great Northern Power Development</td>
<td>2.1 Mt/yr</td>
<td>Coal to liquids facility with CO2 for EOR. Start 2018</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Quintana South Heart Project</td>
</tr>
</tbody>
</table>
While CCS Needs the U to make CCUS Viable, CO2-EOR Also Needs the CO2 from CCUS

- While CCS needs the U to make CCUS, CO2-EOR also needs the CO2 from CCUS
- Growth in production from CO2-EOR is now limited by the availability of reliable, affordable CO2.
- If increased volumes of CO2 do not result from CCUS, then these benefits from CO2-EOR will not be realized.
- The Global CCS Institute reports 60 large-scale integrated projects (LSIPs) at various stages of the asset life cycle.
- Of the projects in operation, under construction, or nearing final investment decisions, 74% (20 of 27) are using or intend to use captured CO2 for CO2-EOR.
Oil Recovery and CO2 Storage Potential in World’s Oil Basins*

<table>
<thead>
<tr>
<th>Region</th>
<th>Technical CO₂-EOR Oil Recovery (Billion Barrels)</th>
<th>Associated CO₂ Demand/Storage Capacity (Billion Metric Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Asia Pacific</td>
<td>47</td>
<td>13</td>
</tr>
<tr>
<td>2. C. &amp; S. America</td>
<td>93</td>
<td>27</td>
</tr>
<tr>
<td>3. Europe</td>
<td>41</td>
<td>12</td>
</tr>
<tr>
<td>4. FSU</td>
<td>232</td>
<td>66</td>
</tr>
<tr>
<td>5. M. East/N. Africa</td>
<td>595</td>
<td>170</td>
</tr>
<tr>
<td>6. NA/Other</td>
<td>38</td>
<td>11</td>
</tr>
<tr>
<td>7. NA/U.S.</td>
<td>177</td>
<td>51</td>
</tr>
<tr>
<td>8. S. Africa/Antarctica</td>
<td>74</td>
<td>21</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,297</td>
<td>370</td>
</tr>
</tbody>
</table>

* Includes potential from discovered and undiscovered fields, but not future growth of discovered fields.

Source: IEA GHG Programme/Advanced Resources International (2009)
“Next Generation” CO2-EOR Technologies

1. Advanced reservoir characterization (to map residual oil and reservoir heterogeneity)
2. Combination horizontal/vertical wells plus “smart” well technology (to better contact bypassed oil)
3. CO2 mobility and flow path control agents (to improve reservoir conformance)
4. Increased volumes of efficiently targeted CO2 (to improve oil recovery efficiency)
5. Near-miscible CO2-EOR technology (to expand CO2-EOR to additional oil reservoirs)
6. Advanced reservoir surveillance and diagnostics technology (to “see and steer” the CO2 flood)
## Life Cycle Analyses of the Integration of “Next Generation” CO2 Storage with EOR

<table>
<thead>
<tr>
<th></th>
<th>“Next Generation”</th>
<th>“Second Generation” CO$_2$-EOR &amp; Incremental Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO$_2$-EOR</td>
<td>CO$_2$-EOR</td>
</tr>
<tr>
<td><strong>CO$_2$ Storage</strong> (million metric tons)</td>
<td>32</td>
<td>76</td>
</tr>
<tr>
<td><strong>Storage Capacity Utilization</strong></td>
<td>22%</td>
<td>53%</td>
</tr>
<tr>
<td><strong>Oil Recovery</strong> (million barrels)</td>
<td>92</td>
<td>180</td>
</tr>
<tr>
<td><strong>% Carbon Neutral</strong>*</td>
<td>74%</td>
<td>90%</td>
</tr>
</tbody>
</table>
Potential Barriers to Lower Cost, Publicly Acceptable CO2 Supplies for CO2-EOR

- Limitations of today’s CO2-EOR technology
- Increased operator knowledge, comfort with, and willingness to pursue CO2-EOR
  - Reducing the uncertainty of CO2-EOR economics
- Achieving both requires research on and demonstration of “next generation” CO2-EOR technologies
  - As well as possible financial incentives to promote CO2 supplies for CO2-EOR
- Willingness/ability of regulators to permit/encourage CO2-EOR and associated CO2 storage
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   • Case
   • Prospect

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1. CO2-EOR Offers Large CO2 Storage Capacity Potential. 
   CO2-EOR in oil fields can accommodate a major portion of the CO2 captured from industrial facilities.

2. CO2-EOR Needs CCUS. Large-scale implementation of CO2-EOR is dependent on CO2 supplies from industrial sources.

3. CCS Benefits from CO2-EOR. The revenues (or cost reduction) from sale of CO2 to EOR helps CCS economics, overcomes some barriers, while producing oil with a lower CO2 emissions.

Thanks!