Jingbian CCS Project

Shaanxi Yanchang Petroleum (Group) Co., Ltd., China

June 15, 2015
Outline

1. Introduction

2. Objectives and Anticipated Outcomes

3. Description and Relevance

4. CO₂ capture and injection site construction

5. Technical Description

6. Conclusions
1. Introduction

(1) Location

CO₂ Storage Site: Jingbian city, Shaanxi Province, China

Location of Jingbian Field and CCS site (Red box). Source of CO₂ is captured from Yulin Coal Chemical Company of Yanchang Petroleum in Yulin City (Blue box).
1. Introduction

(2) Project Goals

To utilize the CO$_2$ captured from coal chemical company and implement CO$_2$-EOR and CO$_2$ sequestration in Ordos Basin.

- To capture CO$_2$ through the use of low-temperature methanol wash coal chemical production processes.
- To transport CO$_2$ by trucks and inject CO$_2$ into nearby oil fields instead of water flooding.
- To improve oil recovery through CO$_2$-EOR in ultra-low permeability and porosity reservoir in Ordos Basin.
- To store CO$_2$ permanently and safely underground in Ordos Basin.
## 1. Introduction

### (3) Project Timeline

<table>
<thead>
<tr>
<th>Description</th>
<th>Important Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project start date</td>
<td>January 1, 2012. China Ministry of Science and Technology (MOST) started to support Jingbian CCS Project.</td>
</tr>
<tr>
<td>Research project of the first phase finished</td>
<td>April 30,2015. CO$_2$ will continue to be injected in Jingbian Field.</td>
</tr>
<tr>
<td>CO$_2$ injection start date</td>
<td>September 4, 2012.</td>
</tr>
<tr>
<td>CO$_2$ capture start date</td>
<td>November 29, 2012, at Yulin Coal Chemical Company.</td>
</tr>
<tr>
<td>GCCSI started to sponsor</td>
<td>July 2, 2013.</td>
</tr>
<tr>
<td>Amount of injected CO$_2$</td>
<td>about 43,000 tons on May 31, 2015.</td>
</tr>
</tbody>
</table>
2. Objectives and Anticipated Outcomes

- Planned to improve the efficiency of coal resource utilization and utilize the CO₂ which is the byproduct of coal chemical company of Shaanxi Yanchang Petroleum Group.

- Planned to build 50,000 tons/year CO₂ capture equipment Yulin Coal Chemical Company of Shaanxi Yanchang Petroleum Group in Yulin City, Shaanxi.

- Planned to inject CO₂ in more than 5 wells and get EOR ratio about 5% to 8% at the low porosity and permeability reservoir of Jingbian Field.

- Planned to develop an integrated MMV (Measurement, Monitoring and Verification) technique and formed CO₂-EOR techniques and a CCS demonstration pilot project.
3. Description and Relevance

(1) *Ordos Basin is the largest oil and gas production area in China*

<table>
<thead>
<tr>
<th>Oil &amp; Gas Equivalent production in 2014</th>
<th>Coal Production of Shaanxi in 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yanchang Petroleum Group</td>
<td>Changqing Oil Company (PetroChina)</td>
</tr>
<tr>
<td>13.75 MT</td>
<td>55.45 MT</td>
</tr>
<tr>
<td>520 MT</td>
<td></td>
</tr>
</tbody>
</table>

**Fossil Fuel Reserves of Shaanxi Yanchang Petroleum Group in Ordos Basin**

<table>
<thead>
<tr>
<th></th>
<th>Crude Oil</th>
<th>Natural Gas</th>
<th>Shale Gas</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proved Reserves</td>
<td>$23 \times 10^8$ t</td>
<td>$3374 \times 10^8$ Nm$^3$</td>
<td>$290 \times 10^8$ Nm$^3$</td>
<td>$150 \times 10^8$ t</td>
</tr>
</tbody>
</table>
3. Description and Relevance

(2) The excessive production of fossil fuels leads to large CO$_2$ emission

- CO$_2$ emission of Shaanxi Province was 133 million tons in 2005 and 234 million tons in 2011 roughly estimated by Liu et al. (2013). The average CO$_2$ emission per person in Shaanxi is 1.6 times as that in China.

- There are still ten large coal chemical projects under construction in Shaanxi. By 2016, when these projects put into operation, CO$_2$ emissions in Shaanxi will increase 180 million tons.
3. Description and Relevance

(3) Large CO₂ emission leads to Climate Change in Shaanxi

The estimated Shaanxi provincial average temperature curves from year 1990-2100 (Shaanxi Meteorological Administration, Jiwen Du, 2009)

Yulin City of Shaanxi is threatened by desertification and in the desert margin.

- Large amounts of CO₂ emission caused a fast-rising average temperature and climate change in Shaanxi Province.

- Climate change intensified the severity of dust storm and desertification in the north of Shaanxi.
3. Description and Relevance

- A warmer climate impacts on fruits through over-ripening, drying out, rising acidity levels, and greater vulnerability to pests and disease, resulting in changes in fruits quality, production, etc.

- If temperature increased 1 degree Celsius in Shaanxi, Shaanxi would not be the world's largest high quality (Fuji) apple planted area.

- Highest temperature in Shaanxi breaks record every year and makes worse drought, poor harvest and drinking water supply.


The high temperature broke record in Shaanxi. Fengcun Reservoir of Sanyuan, Shaanxi nearly dried up on Aug 2, 2014.
3. Description and Relevance

(4) China’s Action on Climate Change

- On Nov. 12, 2014, China promised that its emissions would peak “around” 2030 on China-US Joint Announcement on Climate Change.

- National Medium- and Long-term Program for Science and Technology Development (2006-2020), China's National Climate Change Program, China's Scientific and Technological Actions on Climate Change, National 12th Five-Year Plan on Science & Technology Development listed CCS as key technology to mitigate climate change.

- Shaanxi is selected as one of the first batch of selected localities to promote low carbon pilot projects in 2010 when China launched a national “low-carbon province and low-carbon city” experimental project.
<table>
<thead>
<tr>
<th>Year</th>
<th>Sponsor</th>
<th>Activity</th>
<th>Funding (Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>MOST</td>
<td>CO₂-EOR pilot test in Chuankou oil-field</td>
<td>RMB 3.12</td>
</tr>
<tr>
<td>2010</td>
<td>Shaanxi Yanchang Petroleum Group</td>
<td>Systemly study CO₂-EOR in Ordos Basin, China</td>
<td>RMB 4.8</td>
</tr>
<tr>
<td>2011</td>
<td>MOST &amp; Shaanxi Yanchang Petroleum Group</td>
<td>CO₂ capture from coal chemical industry and CO₂-EOR demonstration project in North Shaanxi</td>
<td>RMB 56.1</td>
</tr>
<tr>
<td></td>
<td>US-China Clean Energy Research Center</td>
<td>Integration of Enhanced Oil Recovery with CO₂ Storage in Mature Oil Fields of the Ordos Basin, China</td>
<td>RMB 0.6</td>
</tr>
<tr>
<td>2012</td>
<td>MOST &amp; Shaanxi Yanchang Petroleum Group</td>
<td>Shaanxi Yanchang Petroleum Group and Northwest University started the first CCS-EOR pilot project in Jingbian Field</td>
<td>RMB 8.92</td>
</tr>
<tr>
<td>2013</td>
<td>GCCSI</td>
<td>China-Australia international demonstration project of CCUS integration</td>
<td>AUD 2.30</td>
</tr>
<tr>
<td>2013</td>
<td>Government of Shaanxi</td>
<td>CCS technology and pilot test of CO₂-EOR in North of Shaanxi</td>
<td>RMB 0.3</td>
</tr>
</tbody>
</table>
(1) CO$_2$ Capture and Transportation

- Yulin Coal Chemical Company of Shaanxi Yanchang Petroleum Group will produce acetic acid 1 million tons/year. In its first phase, it has been producing acetic acid about 200,000 tons/year with CO$_2$ emission about 52,000 tons/year since March, 2011.

- In November of 2012, the CO$_2$ capture equipment (50,000 tons/year) was put into operation in Yulin Coal Chemical Company.
The capture technology is rectisol, the CO₂ concentration of product is about more than 99.9%. The cost for CO₂ capture is about USD18.8.

CO₂ was transported from Yulin city to Jingbian Field by two 20 tons tankers and is now by four 25 tons tanks rented from a private company.
(2) CO$_2$ injection site construction

Injection site construction includes: CO$_2$ storage tank, pumping stations, field stations, road to CO$_2$ injection wells, parking lot and area of well site.
(2) CO$_2$ injection site construction

- Five CO$_2$ injection wells are located in the existing cluster well platform (Jing 45543 well platform of Qiaojiawa area) that saved the investment.

- The designed flexible CO$_2$ injection equipment makes full use of limited area in one platform.

- CO$_2$ injection wellhead equipment has been replaced by anticorrosion material.
4. CO₂ Capture and Injection Site Construction

(3) CO₂ recycling

The facility of CO₂ captured and separated from production well is being developed by Shaanxi Yanchang Petroleum Group, China Huaneng Group and Hunan University. The method of CO₂ removal and separation is amine absorption based on the low energy consumption.

Pilot-plant of CO₂ removal and separation in Yanchang Petroleum Group
(1) Geology Background of Jingbian Field

- Jingbian Field is located in central Ordos Basin in northern Shaanxi slope.
- The oil production was 350,000 tons in 2003, 960,000 tons in 2011 and 1 M tons in 2012.
- Initial average production rate is about 1.6 tons/day after being fractured and without nature productive ability.

<table>
<thead>
<tr>
<th>Jurassic</th>
<th>Upper</th>
<th>Middle</th>
<th>Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fenfanghe Fm.</td>
<td>Anding Fm.</td>
<td>Yanan Fm.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zhiluo Fm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yan 9</td>
<td>Yan 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reservoir</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reservoir</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fuxian Fm.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Triassic</th>
<th>Upper</th>
<th>Middle</th>
<th>Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yanchang Fm.</td>
<td>Zhifang Fm.</td>
<td>Heshanggou Fm.</td>
</tr>
<tr>
<td></td>
<td>Chang 1</td>
<td>Chang 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chang 3</td>
<td>Chang 4+5</td>
<td></td>
</tr>
<tr>
<td>Chang 6</td>
<td>Chang 6 1</td>
<td>Chang 6 2</td>
<td>Chang 6 3</td>
</tr>
<tr>
<td>Chang 7</td>
<td>Chang 7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ordos Basin

Jingbian Field

100 km
## Reservoir Parameters in Jingbian Field

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Baseline</th>
<th>Monitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>44</td>
<td>Measuring</td>
</tr>
<tr>
<td>Primary oil viscosity (mPa.s)</td>
<td>4.84</td>
<td></td>
</tr>
<tr>
<td>Primary oil density (g/cm³)</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>Reservoir depth (m)</td>
<td>1550</td>
<td></td>
</tr>
<tr>
<td>Residual oil saturation (%)</td>
<td>42.2</td>
<td></td>
</tr>
<tr>
<td>Pore pressure (MPa) near injection well</td>
<td>1.5~3 (before injection) 12 (in situ reservoir) Measuring. Estimated 20-22 MPa</td>
<td></td>
</tr>
<tr>
<td>Pore pressure (MPa) near production well</td>
<td>1.5~3</td>
<td>Increasing</td>
</tr>
<tr>
<td>Permeability (×10⁻³μm²)</td>
<td>0.5~3.5</td>
<td>Decreased obviously</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>9-12</td>
<td>Decreased 0.61%~3.66%</td>
</tr>
<tr>
<td>GOR (m³/t)</td>
<td>54~76</td>
<td></td>
</tr>
<tr>
<td>Gas gravity</td>
<td>1.1545</td>
<td></td>
</tr>
<tr>
<td>Salinity (PPM) CaCl₂</td>
<td>50,520-95,110</td>
<td>171,500</td>
</tr>
<tr>
<td>PH</td>
<td>5.5</td>
<td>5.38</td>
</tr>
</tbody>
</table>
5. Technical Description

(2) History of Jingbian Field

- Before 2003, the private companies had begun drilling for oil and gas for over 10 years.
- In 2003, Yanchang Petroleum Group owned Jingbian Field.
- August 2007, it started oil production after fracturing.
- March 2008, it began injection water for EOR. After 12 months oil production declined 74%.
- The average fluid production was 0.5 tons per day, where oil production was 0.18 tons.
- Water flooding effect was not obvious in this area.

- The reservoirs of this area is low porosity and low permeability.
- Natural energy is low and the transmissibility is poor.
- The reservoir pressure and flow capacity drops quickly.
5. Technical Description

(3) Geological Characterization

Location of CCS-EOR site in Jingbian Field
Reservoir Section

**Planned**

- 20 CO₂ injection wells
- Oil producing wells: 70
- Closed water wells outside: 19
- Area: 7.41 km²
- Controlled reserves: 3.32 MT

**First batch wells**

- 10 CO₂ injection wells
- Main oil producing wells: 35
- Area: 4 km²
- Controlled reserves: 1.79 MT
5. Technical Description

(4) CO$_2$-EOR lab study

CO$_2$-EOR VS Pressure

<table>
<thead>
<tr>
<th>Experiment Pressure (MPa)</th>
<th>Volume of gas injection (%P.V.)</th>
<th>Oil recovery (%)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.3</td>
<td>75.45</td>
<td>70.48</td>
<td>Immiscible</td>
</tr>
<tr>
<td>22</td>
<td>94.9</td>
<td>86.78</td>
<td>Immiscible</td>
</tr>
<tr>
<td>22.4</td>
<td>98.76</td>
<td>90.14</td>
<td>Miscible</td>
</tr>
<tr>
<td>23.5</td>
<td>100.06</td>
<td>90.86</td>
<td>Miscible</td>
</tr>
<tr>
<td>25.3</td>
<td>101.6</td>
<td>91.52</td>
<td>Miscible</td>
</tr>
</tbody>
</table>

Jingbian Field CO$_2$ miscible displacement pressure test of Chang 6$_2$--Slim tube experiment

Formation

<table>
<thead>
<tr>
<th>Caprock fracture pressure (MPa)</th>
<th>Chang4+5$_1$</th>
<th>Chang4+5$_2$</th>
<th>Chang6$_1$</th>
<th>Chang6$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.5~23.1</td>
<td>19.8~22.8</td>
<td>16.7~23.5</td>
<td>24.8~25.2</td>
<td></td>
</tr>
<tr>
<td>21.9</td>
<td>20.7</td>
<td>20.9</td>
<td>24.9</td>
<td></td>
</tr>
</tbody>
</table>
Factors influencing CO$_2$ -EOR

Permeability

High speed CO$_2$ injection → High injection pressure → Obvious miscible effect → High CO$_2$–EOR efficiency
WAG and Gas injection enhance oil recovery curves (permeability grade is 30)

Injection methods

- CO2 injection recovery rate
- WAG injection recovery rate
- Water content by CO2 injection
- Water content by WAG

Injection opportunities

When water content reached 60%, 80%, 90% and 98% during water injection

- CO2 injection pressure
- WAG injection pressure
- Produced GOR by CO2 injection
- Produced GOR by WAG

Oil recovery increased 8.41% and final oil recovery reached 33.73% by CO2 injection;
Oil recovery increased 20.95% and final oil recovery reached 44.70% by WAG.
Breakthrough by CO2 injection is faster than that by WAG.
5. Technical Description

Gas oil ratio, Oil recovery level, oil displacement rate and water rate curves under different CO₂ injection pattern.

WAG11—After Injecting CO₂ three months, change to water injection three months.

WAG12—After Injecting CO₂ three months, change water injection six months.

WAG21—After Injecting CO₂ six months, change to water injection three months.
## 5. Technical Description

### (5) Field experiment of $CO_2$-EOR

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Injection Date/Status</th>
<th>Started Injection Pressure (MPa)</th>
<th>Current Injection Pressure (MPa)</th>
<th>Accumulated Injection Volume (t)</th>
<th>Current Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>45543-03</td>
<td>Sep.4, 2012</td>
<td>4.0</td>
<td>6.0</td>
<td>1724.78</td>
<td>Stopped in Nov, 2012 and reinjected in March, 2014</td>
</tr>
<tr>
<td>45543-05</td>
<td>Mar.23, 2013</td>
<td>1.6</td>
<td>8.7</td>
<td>7808.95</td>
<td>Normal</td>
</tr>
<tr>
<td>45543-08</td>
<td>June 8, 2014</td>
<td>4.0</td>
<td>5.8</td>
<td>254.20</td>
<td>Normal</td>
</tr>
<tr>
<td>45543-09</td>
<td>June 8, 2014</td>
<td>3.5</td>
<td>4.5</td>
<td>243.1</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Accumulated volume of $CO_2$ injection till June 19, 2014: 15736.4 t

Accumulated $CO_2$ injection was 43,000 tons by the end of May, 2015.
Injection curves in Jing-45543 injection well station. Note the injection effects before CO₂ injection (before Sep. 2012) and after CO₂ injection (after Sep. 2012). (Courtesy Chunxia Huang).

After injecting CO₂ 13 months, the cumulative increasing oil production was 616 tons.

5. Technical Description

(5) Field experiment of CO₂-EOR
Injection curves in Jing-45543 injection well station. Currently there are 5 CO₂ injection wells (after Sep.2012). (Courtesy Chunxia Huang).

For these 5 well groups, before CO₂ injection the oil production was 88 tons per month, and after CO₂ injection the oil production is 140 tons per month. The oil production increased about 60%. Oil recovery increased 5.73% comparing with water recovery.
5. Technical Description

(6) Measurement, Monitoring and Verification and CO₂-EOR

**What we are studying in Jingbian Field?**

- Storage volume, structural and stratigraphic traps, fault seal, seal thickness, CO₂ capillary pressures, geomechnics, geochemistry, reservoir simulation, etc.
- Confirmation of wellbore integrity, and anticorrosion, CO₂ plume movement.
- Confirmation of secondary trapping and safety of caprock.
- Fast and online monitoring techniques near surface and at atmosphere.
- Environmental effect of CO₂ leakage (Soil, groundwater, temperature, animals, plants, microbe, etc.).
- More accurate reservoir parameters from well log analysis and rock sample.
- Efficiency of CO₂-EOR and Injection Strategy.
5. Technical Description

(7) Geophysical Methods

Before CO₂ injection in Jingbian Field in early 2012, Yanchang Petroleum Group agreed to acquire 5 km² 3D seismic baseline and monitoring data two times in Jingbian CCS-EOR site. Australia GCCSI has also funded part of 4D seismic acquisition.

We also planned time-lapse well logging and seismic rock physics experiment. Seismic rock physics experiment is still in testing.

3D seismic baseline data has not been acquired in Jingbian Field. The reasons are as below:
The cost of 4D seismic acquisition we proposed was lower than the geophysical companies wanted.

The rugged surface and thick loess conditions in loess plateau of Ordos Basin has been the main reasons that lead to poor seismic acquisition quality.

The drop from hill to valley is about 100 meters. Seismic static correction has been and will still be problems in this area.

Continuing global warming and historically long-term droughts in northern of Ordos Basin caused the underground water table decline quickly.
5. Technical Description

4D seismic survey in Wuqi Field

Topography of loess plateau in Wuqi Field
5. Technical Description

Designed baseline 3D seismic acquisition area in Wuqi Field.

Topography in Wuqi Field.

Designed baseline 3D seismic geometry (fold and azimuth)
Shot gathers obtained from different depth of dynamite source

- 12m
- 15m
- 16m
- 18m
- 21m
- 24m
- 27m
- 30m

Shot gathers obtained from different explosive charge of dynamite source (4X6kg means four shots with 6 kg size of charge each shot)

Source line interval
Source interval
Receiver line interval
Receiver interval
Max fold
Geometry
Shot number
Area

- 200 m
- 50 m
- 200 m
- 25 m
- 144
- 4*24 line
- 100 /km²
- 10.5 km²

Receiver elevation of receiver location in two test seismic line in Wuqi.
5. Technical Description

Fluid elastic properties of mixed CO$_2$+Oil+Brine

Baseline and monitor 3D seismic processing, East China

Shear wave velocity prediction at different depth.
5. Technical Description

(8) Geology Study

- Analysis of geological controlling factors of CO$_2$ sequestration

- CO$_2$ flooding reservoir performance analysis of demonstration area

- Evaluation of caprock sealing ability

- Reservoir and caprock micro-sealing difference analysis
图例

Microfaces of Chang 6_2

Sand distribution of Chang 4+5_1

Microfaces of Chang 4+5_1
Histogram of porosity, permeability and water saturation of reservoir

Well log interpreted porosity

Core sample porosity

Well log interpreted permeability

Core sample permeability

Well log interpreted water saturation

Core sample water saturation
Efficiency of different displacement ways

Efficiency improved by different displacement ways

Porosity and permeability variation before and after CO₂ flooding

Oil saturation contour of Chang 6₂ overlaid with oil production
Thickness of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.

Porosity of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.

Oil saturation of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.

Permeability of Chang 6 reservoir. (a) Chang 6_1; (b) Chang 6_2; (c) Chang 6_3.
Chang 6₂ formation fracture pressure -vertical stress.

Chang 6₁ formation fracture pressure -vertical stress.

Chang 4+5₂ formation fracture pressure -vertical stress.

Chang 4+5₁ formation fracture pressure -vertical stress.
Regional seals Chang 4+5_1 (Left): accumulated average thickness of shale is 21.92 m. In the CO_2 injection area (red square), the average thickness of shale is 22 m. The accumulated thickness of shale can be up to 24 m or more. The overall thickness of seal is relatively stable. It meets the requirements of trapping CO_2 or second trapping.

Interbed Chang 6_2 (Right): an average thickness of shale is about 13.86 m. CO_2 injection (red square) is in the thinnest area of shale. However, thick shale on both sides of injection area may seal CO_2 laterally into the reservoir.
Sealing Ability of Caprock

We defined a comprehensive assessment index $A$ according to macroscopic and microcosmic parameters as

$$A = \frac{hr_m P_0 S_o}{Zk}$$

Where $h$ is stacking thickness of caprock; $r_m$ is mudstone stratum ratio; $P_0$ is displacement pressure; $S_o$ is oil saturation; $Z$ is burial depth and $k$ is pressure coefficient.

<table>
<thead>
<tr>
<th>Caprock Comprehensive Assessment Level</th>
<th>I -The best</th>
<th>II -Good</th>
<th>III -Medium</th>
<th>IV -Poorer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensive Assessment Index $A$</td>
<td>$A&gt;3.2$</td>
<td>$2.2&lt;A&lt;3.2$</td>
<td>$1&lt;A&lt;2.2$</td>
<td>$A&lt;1$</td>
</tr>
<tr>
<td>Mudstone thickness (m)</td>
<td>25.91</td>
<td>21.49</td>
<td>16.92</td>
<td>11.14</td>
</tr>
<tr>
<td>Displacement pressures (MPa)</td>
<td>6.38</td>
<td>6.31</td>
<td>6.28</td>
<td>6.24</td>
</tr>
<tr>
<td>Mudstone stratum ratio</td>
<td>0.71</td>
<td>0.59</td>
<td>0.45</td>
<td>0.29</td>
</tr>
<tr>
<td>Oil saturation (%)</td>
<td>46.98</td>
<td>45.78</td>
<td>45.11</td>
<td>45.13</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>1548.83</td>
<td>1552.28</td>
<td>1554.38</td>
<td>1558.84</td>
</tr>
<tr>
<td>Pressure coefficient</td>
<td>0.86</td>
<td>0.87</td>
<td>0.86</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Modeling of CO₂ Storage Body

Geologic Structure Model

Porosity Model

Permeability Model

Displacement pressure model

Oil saturation model

CO₂ leakage risk prediction

CO₂ saturation distribution vertically
We estimate that the maximum volume for CO$_2$ storage in Chang 6$_2$ unit is $1.4 \times 10^7$ m$^3$, CO$_2$ capacity is 127,000 t.
5. Technical Description

(9) Environmental monitoring

• Fast monitoring techniques near surface and at atmosphere.

• The impact of CO$_2$ leakage on environment.
  – Soil, groundwater, temperature, human health, animals, plants, etc.
  – Purity of CO$_2$ (CO$_2$, H$_2$S, CO, SO$_2$, NO$_x$)

• Quantitatively prove the leakage of CO$_2$?

Remote sensing image on May 11, 2011
Combining the sample collection device and isotope measuring instrument to establish an assay method for $^{13}$C and $^{14}$C.

- Using this method, we measured the content of $^{14}$C and $^{13}$C in near-surface before and after CO$_2$ injection and used the Keeling Curve to determine the background value.

  - In March, the intercept -6.8 is approaching the value of $^{13}$C in the air, -8.0; In August, the intercept -29.5 is approaching the value of $^{13}$C in the vegetation, -26.

- After injection of CO$_2$, we have measured the near-surface $^{13}$C content around the wellhead and 50~100 m from the wellhead. Using the Keeling Curve, the linear intercept is -9.7 in March and -17.6 in August, respectively.
The relationship between the dissolution rate and the etching apparatus time of CO₂.

The relationship between the dissolution rate and the partial pressure of CO₂.

- Dissolved CO₂ in water may accelerate the digestion of metal ion in mineral, the dissolving-out amount is related to the etching time and pressure of CO₂.
- If the CO₂ came up into the ground water, the content of metal ion in ground water will be increased and water quality will be changed.
Environmental monitoring near Jingbian CCS site.
The impact of CO₂ on the morphological indexes of C3 crops.
The impact of CO$_2$ on the biomass of C3 crops.
The impact of CO$_2$ on the soil composition and properties.
The impact of CO$_2$ on the population of microorganisms.
Selection of indicative bacteria

By comparing the DGGE electrophoresis of C4 crops under different CO₂ concentration, the study shows:

- In soil of planting corn, when the CO₂ concentration was at 80000 ppm, *Desulfomicrobium thermophilum* can be used as an indicative bacteria.——1

- In soil of planting sorghum, when the CO₂ concentration is at 10000 ppm, *Burkholderia cepacia*, *Brucella suis*, *Thiohalocapsa halophil*, *Porphyromonas gingivicanis* and *Bacteroides intestinalis* can be used as indicative bacteria.——5

- In soil of planting millet, when the CO₂ concentration was at 10000 ppm, *Brucella suis*, *Thiohalocapsa halophil*, *Pelomonas aquatica*, *Hydrogenophaga intermedia*, *Prevotella dentalis* and *Sphingomonas oryziterrae* can be used as indicative bacteria.——6

- *Brucella suis* and *Thiohalocapsa halophil* were the common soil indicative bacteria microbes of sorghum and broom corn millet at the 10000 ppm of CO₂ concentration.

- DGGE bands of millet root soil bacteria were not significantly different, it had difficulty to choose the indicative bacteria microbe.

- There were 10 indicator bacteria microbes being used as indicators of CO₂ leakage.
CO₂ impact for animals

- CO₂ impact for mouse
  - Semi-lethal concentration
  - The behavior influence
  - The blood gas influence

- CO₂ impact for fish
  - Water quality
  - Semi-lethal flow of CO₂
  - Blood gas
5. Technical Description

(10) *Anticorrosion and wellbore integrity*

**Anticorrosion**

During CO$_2$ injection process, the corrosion may severely damage the down-hole tubular system.

- Simulating CO$_2$ injection under different environmental condition.
- Obtain the corrosion rule of the typical materials.
- Sift and evaluate coating, corrosion and scale inhibitor.
- Provided the support for corrosion control.
5. Technical Description

(11) Anticorrosion and wellbore integrity

Corrosion effects during CO₂ flooding

Environmental factors

Pressure
Temperature
PH value
Medium ion
Organic acid
Microorganism
H₂S
Dissolved O₂
Flow rate
Flow pattern

Material factors

Alloying element
Thermal treatment
Metallographic structure
Corrosion product film

\[
\begin{align*}
\text{CO}_2 + \text{H}_2\text{O} & \rightleftharpoons \text{H}_2\text{CO}_3 \\
\text{Fe}_3\text{O}_4 & \rightarrow \text{FeOOH} \\
\text{H}_2\text{CO}_3 & \rightarrow \text{H} + \text{HCO}_3^- \\
\text{Fe} + 2\text{H}_2\text{O} & \rightarrow \text{Fe(OH)}_2 + 2\text{H}^+ + 2e \\
\text{Fe(OH)}_2 + \text{H}_2\text{CO}_3 & \rightarrow \text{FeCO}_3 + 2\text{H}_2\text{O} \\
\text{FeCO}_3 + \text{HCO}_3^- & \rightarrow \text{Fe(CO}_3)_2^- + \text{H}^+ 
\end{align*}
\]
Anticorrosion

- Screening corrosion inhibitor.
- TK70 coating protection.
- Wellbore corrosion protection device.
- Coating + sacrificial anode technology.
- Impressed current cathode protection optimization techniques.

Inside and outside of the tubing corrosion rate is less than 0.076 mm/a.
We detected the cementing quality of cased well by logging Acoustic Variable Density in the north of the Jingbian Field.

Imidazoline and modified imidazoline inhibitor were used in Jingbian Field.

Test condition: Temperature is 55 ℃, flow speed is 0.3 m/s, CO₂ pressure is 5MPa and content is 80 ppm.
6. Conclusions

- Cheaper CO₂ source that captured from coal chemical plant makes the full chain Jingbian CCS project into reality.

- CO₂-EOR recovered more oil than water injection in low porosity and permeability reservoir in Ordos Basin. This inspires more companies to invest in CCS in Ordos Basin and China.

- MMV study shows the safety of CO₂ geological storage in Jingbian CCS site.

- Current CO₂ leakage from borehole is less than 2% and would affect environment and environmental monitoring. When our CO₂ recycle equipment put into use, there will be no CO₂ leakage from wellbore.
6. Conclusions

- It is the first time in China for us to acquire baseline surface soil, water, plants and other monitoring data. The integrated and life time MMV is necessary and need more funding.

- It is not easy for us to make Jingbian CCS Project into practice. There are more obstacles for CCS in China than developed countries. However, there are also more opportunities for CCS in China.

- Current Jingbian CCS demonstration does not make money, however, it creates significant social benefits and environmental benefits for our society.
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Jinbian CCS is one small step for Yanchang, one giant leap for China!

Mr. Peng Sizhen of MOST visited Jingbian CCS site.

Experts from WVU visited Jingbian CCS site.

Experts from DOE of U.S visited Jingbian CCS site.

Agreement with GCCSI of Australia.