The Progress and Outlook of Integrated CCUS Demo of Yanchang Petroleum

Speaker: Gao Ruimin

China. Research Institute of Shaanxi Yanchang Petroleum (Group) Co., Ltd

SEP 9, 2014
Outline

1. Profile of Yanchang Petroleum
2. Background and Advantages
3. Research and Development
4. Progress of Field Applications
5. Planning
1. Profile of Yanchang Petroleum

◆ **History:** Shaanxi Yanchang Petroleum (Group) Corp. Ltd is one of the four qualified enterprises for oil and gas exploration in China. The first oil well in mainland China was drilled in this area 108 years ago. It has made an important contribution to the national construction.

◆ **Businesses:** involve oil and gas exploration and production, oil refining, storage and transportation, oil-selling, mining industry, new energy, equipment manufacturing, engineering design and construction, technology research and development and financial service.
1. Profile of Yanchang Petroleum

**Benefits:** Yanchang have produced crude oil by 12.54 million tons and refined crude oil by 14.03 million tons in 2013; The sales revenue of 2013 is 186.5 billions, and has entered the world top 500 enterprises.

**Resource:** Yanchang located in Ordos basin, the proved reserves of oil is 2.5 billion tons, the proved reserves of natural gas is 330 billion m³, the proved reserves of coal is 15 billion tons.

**Objective:** Yanchang will have endeavored to realize 500 billion Yuan of operating revenues by the end of “The Thirteen Five-Year Plan”, and entered into the top 300 enterprises of the world.
2. Background and Advantages

**Background**

- **Emission reduction pressure:** With the rapid economic development, as the biggest producer, consumer and emitter of carbon, China is facing the growing pressure of carbon emission reduction.
- **Enterprise responsibility:** Coal chemical industry of YanChang releases plenty of high-concentration carbon dioxide, which needs to be handled reasonably.
- **Economic development:** As a comprehensive developed enterprise, YanChang realizes economic sustainable development for both northern Shaanxi district and the company itself.
- **Problem solving:** During development process, YanChang needs to overcome the problem of low permeability, unstable yields, water shortage and fragile environment.

Through out the development of CCUS project, we must combine “carbon capture-EOR-carbon storage-carbon reduction” together, and it’s the inevitable choice of YanChang to realize emission reduction and industry sustainable development.
2. Background and Advantages

Advantages

There are abundant coal, oil and natural gas resources belonging to Yanchang petroleum in the north of Shaanxi province, which lays the foundation for the integrated CCUS project.

1) Energy saving and carbon reduction by comprehensively making use of coal, oil and gas

Yanchang Petroleum is rich in resources such as coal, oil, gas, and so on, which can bring complementation of carbon molecules and hydrogen molecules by comprehensive utilization. The innovative jointing of coal chemical and oil&gas Chemical can make CO$_2$ emission reduce sharply, thereby enhance energy efficiency.
2. Background and Advantage

2) CO\textsubscript{2} capture and transportation with low-cost

- The purity of CO\textsubscript{2} that come from coal chemical industry of Yanchang is very high, captured devices adopt Rectisol process with the characteristic of low cost and energy-consuming, the cost of running capture devices is just 18 $. 
- The cost of CO\textsubscript{2} transportation is low because oil field and coal chemical plants locate in the same areas.

3) Broad prospects of CO\textsubscript{2}–EOR

- Yanchang oil reservoir belong to ultra-low permeability, the oil recovery is 10%, CO\textsubscript{2} flooding can enhance oil recovery by 5-10%, therefore ensure sustained oil production.
- replacing water flooding with CO\textsubscript{2} flooding can save huge volume of water in north of Shaanxi which is water resource shortage.
- benefit of CO\textsubscript{2}–EOR can make up for CCUS cost, so that both social and economic benefits can be achieved.

4）Advantages of CO\textsubscript{2} fracturing and enormous demand

- Most of wells need to be fracturing for producing, besides saving lots of water, CO\textsubscript{2} fracturing can increase production by 50%.
4) Ample storage volume and Stable geologic structure

- The geology of Ordos basin is stable and simple structure with less fault, it is safe for CO₂ storage, and is the most advantageous areas of CO₂ storage in China.
- According to preliminary estimate, reservoir can storage CO₂ by 500~1000 million tons and deep brine aquifers can storage CO₂ by 10 billion tons in Ordos basin, Yanchang Oil-field can storage CO₂ by 180 million tons.
- The reservoir depth is 1~3Km, it is better for CO₂ injected by supercritical state.
5) State-sponsored, Corporate attention, International cooperation

◆ State-sponsored: Yanchang Petroleum got supports from National Development and Reform Commission and Ministry of Science and Technology.

◆ Corporate attention: Yanchang Petroleum invested 300 million ¥ on CCUS, and established working team.

◆ International cooperation: joined in the US-China Advanced Coal Technology Consortia, and established cooperation mechanism with Institute of global CCUS, University of Wyoming, University of West Virginia, University of Regina, Air Products & Chemicals Corp.

<table>
<thead>
<tr>
<th>year</th>
<th>sponsor</th>
<th>Relation Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Planning of national Supporting technical</td>
<td>research of CO₂- EOR in low(ultra-low)permeability reservoir (ChuanKou Oilfield)</td>
</tr>
<tr>
<td>2010</td>
<td>Yanchang Petroleum</td>
<td>research on the matching technology of Yanchang Petroleum CO₂- EOR (300 million)</td>
</tr>
<tr>
<td>2011</td>
<td>Planning of national Supporting technical</td>
<td>Technology Demo of CCS and EOR of Shanbei Coal-chemical Industry</td>
</tr>
<tr>
<td>2012</td>
<td>Planning of national 863</td>
<td>Key technical research of exhaust gas CCUS of coal-fired power plant</td>
</tr>
<tr>
<td>2013</td>
<td>Institute of Australian carbon capture and storage</td>
<td>Demonstration Project of Sino-Australian International Cooperation on CCUS Integration</td>
</tr>
<tr>
<td>2013</td>
<td>Shaanxi government</td>
<td>Key technical pilot test of CO₂- EOR in north of Shaanxi</td>
</tr>
<tr>
<td>2014</td>
<td>Yanchang Petroleum</td>
<td>pilot test of CO₂ flooding and fracturing in north of Shaanxi</td>
</tr>
</tbody>
</table>
3. Research and Development

Since 2007, Yanchang petroleum have researched and developed 4 items of CCUS matching technology under the support of national technical Planning, projects of International cooperation and Yanchang Petroleum Group.
1) Build a set of CO₂ capture multifunction pilot-plant

Research and Development a set of CO₂ capture multifunction pilot-plant which aim at low purity CO₂ (about 20%) and producing CO₂ of recapture, separation, purification and reutilization.

**Index parameter**

- capture capacity: 200kg/d;
- energy consumption: 1.084GJ/t;

**Technical characteristics:** simple technology, high safety factor, low energy consumption, stable performance, low-cost, high purity
Aim at the running coal chemical plant of Yanchang petroleum, developed Rectisol Process technology of CERI by the way of evaporation method, separated and purified no-sulphur Liquid rich methanol that associated with rich CO₂.

Aim at sulphur liquid rich methanol, developed Rectisol Process technology of HNU1 by the way of flashing, compression, drying, dehydration, further enhanced capture capacity and reduced energy consumption.

Aim at associated gas that come from CO₂ flooding process in JingBian oilfield, developed a set of producing CO₂ separated technology, separate and Purify producing CO₂ in oilfield.

<table>
<thead>
<tr>
<th>technology</th>
<th>Capacity (t/h)</th>
<th>Purity (%)</th>
<th>energy consumption (GJ/t CO₂)</th>
<th>Traditional energy consumption (GJ/t CO₂)</th>
<th>Cooling water(t/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERI</td>
<td>8.5</td>
<td>99.6</td>
<td>1.24</td>
<td>2.85</td>
<td>134.46</td>
</tr>
<tr>
<td>HNU1</td>
<td>22.2</td>
<td>99.6</td>
<td>0.62</td>
<td>2.70</td>
<td>135.5</td>
</tr>
<tr>
<td>Capture of producing CO₂</td>
<td>11.09</td>
<td>86</td>
<td>1.08</td>
<td>1.25</td>
<td></td>
</tr>
</tbody>
</table>
1) Built the Criteria of reservoir selection

With taking into account geology, fluid, field development, oil recovery, GOR and so on, developed criteria of reservoir selection for CO₂ flooding and storage in Yanchang oilfield.

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Reservoir number</th>
<th>suitable Reservoir</th>
<th>Not suitable Reservoir</th>
<th>Ratio of suitable Reservoir</th>
<th>Reserves (\times 10^4t)</th>
<th>suitable Reserves (\times 10^4t)</th>
<th>Not suitable Reserves (\times 10^4t)</th>
<th>Ratio of suitable Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>杏子川</td>
<td>13</td>
<td>12</td>
<td>1</td>
<td>0.92</td>
<td>10685</td>
<td>10495</td>
<td>190</td>
<td>0.98</td>
</tr>
<tr>
<td>靖边</td>
<td>15</td>
<td>14</td>
<td>1</td>
<td>0.93</td>
<td>12341</td>
<td>12071</td>
<td>270</td>
<td>0.98</td>
</tr>
<tr>
<td>永宁</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>0.8</td>
<td>25316</td>
<td>24727</td>
<td>588</td>
<td>0.98</td>
</tr>
<tr>
<td>西区</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>1.00</td>
<td>12012</td>
<td>12011</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>七里村</td>
<td>8</td>
<td>1</td>
<td>7</td>
<td>0.13</td>
<td>12691</td>
<td>1934</td>
<td>10757</td>
<td>0.15</td>
</tr>
<tr>
<td>瓦窑堡</td>
<td>16</td>
<td>11</td>
<td>5</td>
<td>0.69</td>
<td>13924</td>
<td>11142</td>
<td>2782</td>
<td>0.80</td>
</tr>
<tr>
<td>......</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>178</td>
<td>150</td>
<td>28</td>
<td>0.84</td>
<td>219138</td>
<td>176274</td>
<td>42864</td>
<td>0.80</td>
</tr>
</tbody>
</table>
# CO₂ Flooding and Storage

## 2) Potential evaluation of CO₂ flooding and storage

<table>
<thead>
<tr>
<th>num</th>
<th>reservoir</th>
<th>Reserves (10⁴t)</th>
<th>Storage capacity (10⁴t)</th>
<th>Enhanced recovery(%)</th>
<th>Utilization coefficient</th>
<th>Storage coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>化子坪区-长2层</td>
<td>1015</td>
<td>265.63</td>
<td>6.99</td>
<td>0.27</td>
<td>0.26</td>
</tr>
<tr>
<td>2</td>
<td>乔家洼-长6</td>
<td>931</td>
<td>209.87</td>
<td>4.03</td>
<td>0.18</td>
<td>0.23</td>
</tr>
<tr>
<td>3</td>
<td>永宁油区-长6</td>
<td>1333.69</td>
<td>357.41</td>
<td>10.83</td>
<td>0.40</td>
<td>0.27</td>
</tr>
<tr>
<td>4</td>
<td>义吴-长4+5、长6</td>
<td>4754.79</td>
<td>1207.39</td>
<td>9.85</td>
<td>0.39</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>定边-延10</td>
<td>424</td>
<td>145.83</td>
<td>10.83</td>
<td>0.31</td>
<td>0.34</td>
</tr>
<tr>
<td>6</td>
<td>郭旗西区-长61</td>
<td>3110</td>
<td>769.90</td>
<td>8.67</td>
<td>0.35</td>
<td>0.25</td>
</tr>
<tr>
<td>7</td>
<td>直罗-埝沟-长2</td>
<td>240</td>
<td>62.42</td>
<td>7.43</td>
<td>0.29</td>
<td>0.26</td>
</tr>
<tr>
<td>8</td>
<td>南区-湫沿山-长6</td>
<td>278.6</td>
<td>62.80</td>
<td>10.52</td>
<td>0.47</td>
<td>0.23</td>
</tr>
<tr>
<td>9</td>
<td>吴起-油沟-长4+5</td>
<td>801</td>
<td>194.25</td>
<td>8.58</td>
<td>0.58</td>
<td>0.56</td>
</tr>
<tr>
<td>10</td>
<td>英旺-庙湾-长8</td>
<td>454.41</td>
<td>156.29</td>
<td>5.51</td>
<td>0.16</td>
<td>0.34</td>
</tr>
</tbody>
</table>

**Model of potential evaluation for CO₂ flooding**
- Ratio of CO₂ dissolve in Original oil
- Ratio of CO₂ dissolve in stratum water
- CO₂ storage capacity calculated under well closed material balance

**Calculated model of storage capacity**
- Immiscible
- Miscible

**Sweeping efficiency**
3) Reservoir engineering methods and experiments evaluation system

Reservoir engineering methods for CO₂ flooding in YanChang ultra-low permeability reservoir.

Development geology: Decrypted reservoir heterogeneous and distribution regularity in detail, built the precise reservoir geologic modeling.

Reservoir evaluation: Analyzed the characteristic of oil productivity, oil-water relationship and development.

Numerical reservoir simulation: Built 3-D geologic model of WuQi and JingBian and conducted history matching.

Experiments evaluation for CO₂ flooding

- heterogeneous of core under control
- overlength core for displacement
- large physical simulation with radial low-permeable seepage

WuQi test site

JingBian test site
4) Matching technology and anti-corrosion for CO₂ flooding

- **Matching technology of injected well**
  - Improved wellhead and injection string
  - Optimized oil tube and packer

- **Matching technology of produced well**
  - Optimized the pumping unit,
    - sucker rod and oil pump

- **Study of anti-corrosion**
  - **Injection well**: carbon steel + packer + inhibitor
  - **Production well**: Comprehensive anti-corrosion + carbon steel + inhibitor

*Graph showing study conditions:
- Temperature: 55°C
- Flow velocity: 0.3 m/s
- CO₂ partial pressure: 5 MPa
- Concentration: 80ppm

*Graph showing coating optimization:
- Anti-corrosive agent optimization
  - Before soaking
  - After soaking
CO$_2$ Flooding and Storage

5）Technology of expanding swept volume

- **stage 1**—WAG
- **stage 2**—modified starch plug channeling of fracture
  characteristic: high strength and remain stable after gelling
- **stage 3**—Small molecule amine plug channeling of high permeable formation
  mechanism: ease to be injected and form a salt with CO$_2$ reacting

modified starch after gelling

Small molecule amine
6) **CO₂ safety-monitoring technology**

<table>
<thead>
<tr>
<th>Monitoring Program</th>
<th>cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>injection well</td>
<td></td>
</tr>
<tr>
<td>Injection parameters (volume, pressure, temperature)</td>
<td>continuous</td>
</tr>
<tr>
<td>production performance</td>
<td>day</td>
</tr>
<tr>
<td>working fluid level</td>
<td>month</td>
</tr>
<tr>
<td>Purity of producing CO₂</td>
<td>continuous</td>
</tr>
<tr>
<td>pressure monitoring</td>
<td>continuous</td>
</tr>
<tr>
<td>component of crude oil</td>
<td>season</td>
</tr>
<tr>
<td>Output profile</td>
<td>2 year</td>
</tr>
<tr>
<td>static pressure</td>
<td>2 year</td>
</tr>
<tr>
<td>water quality</td>
<td>month</td>
</tr>
<tr>
<td>corrosion rate</td>
<td></td>
</tr>
<tr>
<td>reservoir</td>
<td></td>
</tr>
<tr>
<td>tracer material</td>
<td></td>
</tr>
<tr>
<td>formation pressure</td>
<td></td>
</tr>
<tr>
<td>formation water PH</td>
<td></td>
</tr>
<tr>
<td>seismic surveillance</td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td></td>
</tr>
<tr>
<td>Atmospheric CO₂ Purity</td>
<td>Half year</td>
</tr>
<tr>
<td>Soil C₁₃</td>
<td>year</td>
</tr>
<tr>
<td>plant growth</td>
<td>Half year</td>
</tr>
</tbody>
</table>

**Monitoring Program Diagram:**
- **Air:** Infrared Monitor CO₂ Purity
- **Surface:** C₁₃ isotope
- **Wellhole:** Integrity of 3 index
- **Formation:** Tracer, pressure, water, seismic
7) safe system of risk assessment and methodological flow of pre-warning

- **risk identification**
  - Definition of risk identification
  - Leaking channeling of geological storage

- **risk evaluation**
  - Leak evaluation
  - Soil evaluation
  - Integrality of well evaluation

- **risk control**
  - Risk pre-warning
  - Risk remedy

**CO₂ Flooding and Storage**
1) Technological process of portable CO₂ flooding devices and field application

Injection flow of well site: Truck → Storage tank → Feeding pump → Injection pump → Wellhead

Technology of injection CO₂ site

- CO₂ truck
- CO₂ Storage tank
- CO₂ Feeding pump
- Injection pump

- V = 100 m³
- t = -20°C
- P = 2.0 MPa

- Q ≤ 5 m³/hr
- P ≤ 18.0 MPa

- Q ≤ 10 m³/hr
- P ≤ 2.5 MPa
2) Finished Overall design of CO₂ injected process in JingBian oilfield

- 2 CO₂-injection stations, scale 600m³/d;
- built 2 new 3km roads;
- 20km injection pipeline;

**1# station:** locate at 544 well site
- 4 CO₂ storage tanks: V=100m³
- 4 Feeding pumps: 2 running and 2 standby;
- 6 Injection pump: 4 running and 2 standby;
- Meet 15 injection Wells.

**2# station:** locate at 134 well site
- 2 CO₂ storage tanks: V=100m³
- 2 Feeding pumps: 1 running and 1 standby;
- 3 Injection pump: 2 running and 1 standby;
- Meet 5 Injection Wells.
III types of CO₂ fracturing developed by laboratory study and field test

1) CO₂ enhanced Fracturing

Combined with the features that liquid CO₂ are high flow-back, low damage and fit for sand fracturing, we developed CO₂ enhanced fracturing tech that use liquid CO₂ first before hydro fracture. This increased the CO₂ fracturing flow-back rate.

2) CO₂ Foam Fracturing

Taken the foam fluid (liquid CO₂: fracturing fluid to a certain proportion with foam quality >52%) as sand carrying agent, injected into the formation. This tech is water saving and low damage to the formation.
CO₂ Fracturing

3) CO₂ Liquid Fracturing

Fracturing using pure liquid CO₂ as the sand carrying fluid. CO₂ can be drained out of the formation quickly and completely after fracturing with no damage.

◆ Liquid CO₂ pipe flow test

Evaluated for the first time the liquid (supercritical) CO₂ flow friction coefficient, dynamic filtration and dynamic sand carrying capability, which gives theoretical support to CO₂ dry fracturing and parameters optimization.

◆ CO₂ dry fracturing optimization

Considering the pump infusion, established the CO₂ wellbore flow friction plate and optimized dry fracturing parameters.
4. Progress of Field applications

After many years of research and practice, Yanchang got the substantial progress on CCUS

1) Jingbian coal-to-chemicals demonstration project

By Hydrogen-Carbon complementary (more carbon than hydrogen in coal and more hydrogen than carbon in oil and gas), Yanchang petroleum carried out world's first oil-gas-coal comprehensive utilization demonstration projects. The project was put into production on 2014 July, with total investment 26.9 billion RMB, 600,000 tons polyethylene and 600,000 tons polypropylene products per year, and achieve an annual emission reduction 4,350,000 tons.

<table>
<thead>
<tr>
<th>num</th>
<th>JingBian project</th>
<th>JingBian advanced level</th>
<th>International advanced level</th>
<th>Domestic advanced level</th>
<th>Compared with International level</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>methanol production(10^4t/y)</td>
<td>180</td>
<td>165.35</td>
<td>153.12</td>
<td>+8.86%</td>
<td>Same material</td>
</tr>
<tr>
<td>3</td>
<td>energy consumption(GJ/t)</td>
<td>37</td>
<td>48</td>
<td>50</td>
<td>-23.8%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>water consumption(m^3/t)</td>
<td>4.1</td>
<td>10</td>
<td>12</td>
<td>-59.00%</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>CO₂ emission (10^4t/a)</td>
<td>285</td>
<td>720</td>
<td>720</td>
<td>-60.42%</td>
<td>4.35million ton/a</td>
</tr>
<tr>
<td>7</td>
<td>SO₂ emission (t/a)</td>
<td>634</td>
<td>1389</td>
<td>1389</td>
<td>-54.36%</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>wastewater (m^3/h)</td>
<td>83.4</td>
<td>252.9</td>
<td>252.9</td>
<td>-67.02%</td>
<td>Saving water 10 million ton/a</td>
</tr>
<tr>
<td>9</td>
<td>Solid Waste(10^4t/a)</td>
<td>12.8</td>
<td>39.82</td>
<td>39.82</td>
<td>-67.81%</td>
<td>landfill</td>
</tr>
</tbody>
</table>
2) Yulin coal-oil co-refining demonstration project

Based on the technology of heavy oil hydrocracking and coal hydro liquefaction, Yanchang petroleum developed coal-oil co-refining tech, which use residue oil, heavy oil, coal tar and low rank coal as raw materials, played a synergistic effect of coal and heavy oil in the reaction, greatly improved resources transformation efficiency and realize an annual emission reduction 1.8 million tons.

<table>
<thead>
<tr>
<th>project</th>
<th>scale</th>
<th>Construction investment</th>
<th>Energy efficiency</th>
<th>CO₂ emission</th>
<th>Water consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>indirect coal to liquid</td>
<td>1million ton/a</td>
<td>&gt;16 billion</td>
<td>40.5%</td>
<td>7.2ton</td>
<td>&gt;10ton/ton-oil</td>
</tr>
<tr>
<td>direct coal to liquid</td>
<td>1million ton/a</td>
<td>&gt;12 billion</td>
<td>50.26%</td>
<td>5.2ton</td>
<td>10ton/ton-oil</td>
</tr>
<tr>
<td>coal and oil co-refining</td>
<td>0.33million ton/a</td>
<td>≈2.5 billion</td>
<td>70.65%</td>
<td>1.1ton</td>
<td>3.36ton/ton-oil</td>
</tr>
</tbody>
</table>
4. Progress of Field applications

3) Integrated technology of coal tar extraction and synthesis gas in coal (CCSI).

Yanchang petroleum developed it’s own integrated coal tar extraction and synthesis gas in coal (CCSI) technology. At present, lab and small scale pilot experiment has been completed; a bigger 36 tons/d pilot device is being designed.

**Profit analysis:**
Processing 100 million tons of coal per year using CCSI technology:
Raw material cost: 35 billion RMB.
Product value: 236 billion RMB, in which coal tar processing output value are 96 billion RMB and synthesis gas and oil output value are 140 billion RMB.
So, resource added value up to 201 billion RMB.
4) Low-cost CO₂ capture devices on coal chemical industry

Firstly build a set of 50,000 t/a CO₂ capture device in Yulin Coal Chemical Company, using CERI process directly to separate high purity CO₂ products from no sulfur medium voltage methanol rich liquid.

The 80000 ton/year CO₂ with food grade is produced by Shaanxi Xinhua-Xinke Gas Company, the sub-company of Yanchang Petroleum.

The 360000 ton/year CO₂ capture facility construction project has been started by Shaanxi Yanchang China-coal Yulin Energy Chemical Company, the project will be finished by OCT, 2014.
5) CO₂-EOR and storage pilot test

(1) CO₂-EOR and storage field test site of JingBian

Stage 1 JingBian pilot test started in Sep 5, 2012, and had cumulatively injected 180 thousand ton liquid CO₂ with 5 well groups, comparing with estimated oil production decreasing rate by waterflooding, accumulated oil production increased by 900 tons. It will increase 16 well groups in 2015, inject CO₂ by 200 thousand ton/a, and storage CO₂ by 120 thousand ton/a.
4. Progress of Field applications

(1) CO\textsubscript{2}-EOR and storage field test site of WuQi

Stage 2 carried out miscible displacement of EOR in WuQi whose area is 14.8 km\textsuperscript{2}, and had started injection in Aug, 2014. It will increase 36 well groups in 2015, inject CO\textsubscript{2} by 300 thousand ton/a, and storage CO\textsubscript{2} by 180 thousand ton/a.

MMP tube experiment

\[\text{MMP tube experiment} \quad \text{MMP} = 17.8 \text{MPa} \]
6) CO₂ fracturing field apply

（1）Shale gas wells CO₂ fracturing: CO₂ fracturing had been conducted at YanYePing3 well, with 767 m³ CO₂, 728 m³ sand and 20,000 m³ other fracturing fluid. Through this CO₂ enhanced fracturing, single well production and fracturing fluid flow-back rate had been increased.

（2）Natural gas wells CO₂ fracturing: For low pressure tight sandstone gas reservoir, we developed VES-CO₂ foam fracturing technology that increasing the yield obviously. Shi3 well, which applied VES-CO₂ foam fracturing, has increased daily gas production from 6400 m³ to 3,8000 m³, and daily open flow capacity from 2,1500 m³ to 10,0000 m³.
After accumulation of preliminary study and practice, CCUS Planning of YanChang at the end of “thirteen Five-Year Plan” is arranged as follows:

1) Work on allied chemical of coal, oil and gas for carbon reduction; develop clean utilization model of fossil fuel through hydrocarbon complementation and coal refine, reducing more than 1200 tons of carbon a year than traditional coal chemical industry. Focus on the innovation to carry out coal, oil & gas to olefins and coal & oil Co-refinery, significantly reducing carbon and improving fuel efficiency.

◆ **Coal, oil and gas comprehensive translation:** Oil, gas and coal transfer to olefins and hydrogen, producing 600 thousand tons of polyethylene, 600 thousand tons of polypropylene and other products a year.

◆ **coal &oil Co-refinery:** The coal-oil co-refine plant with the scale of 450 thousand tons/a was started in May 2014; The coal tar hydro-refining plant with the scale of 500 thousand tons a year was started in Oct, 2014.
5. Planning

2) Campaign of carbon capture, utilization and storage are arranged as follows:

| **capture** | Based on the existing of 50000 tons/a CO₂ capture, carry out the pre-feasibility of CO₂ capture facilities by the scale of 3.5 million tons/a, improving total capture ability to 4 million tons/a. |
| **transport** | Demo and construct a CO₂ pipeline with total length of 200—300 kilometers and delivery capacity reaches to 4 million tons/a. |
| **flooding and storage** | Construct industrial application base of CO₂-EOR and storage with more than 600 wells, increasing oil production by 1 million tons/a, storing CO₂ by 2.4 million tons/a, enhancing oil recovery by 5%--10%, and realizing recapture and cyclic utilization of CO₂. |
| **fracturing** | Implement CO₂ fracturing by 100 shale and natural gas wells. |
| **teamwork** | Develop a managing excellence team of CCUS, which can undertake CO₂ reduction, capture, storage management and technical work, ensuring healthy and steady development of Yanchang CCUS. |
3) next CCUS research orientation Of Yanchang

◆ CO₂ capture, separation and transportation technology----including optimization and new process simulation of CO₂ capture from coal chemical; economic evaluation of capture-separation technology; liquid and supercritical transportation technology, separation technology of CO₂ from produced oil gas.

◆ Matching technology for CO₂ storage and CO₂ -EOR----including numerical simulation of the injected CO₂ and optimization of injecting scheme.

◆ Monitoring for CO₂ storage and safe displacement----including monitoring of CO₂ storage and safe flooding; monitoring of gas channeling and gas flooding front; monitoring of injecting dynamic and producing dynamic.

◆ CO₂ fracturing technology

◆ Policy and law for CCUS
Technical ideas which combined CCUS with EOR is one of an effective way to realize Carbon Reduction. As an important member of energy chemical industry, Yanchang petroleum is willing to enhance communication, and cooperation with the domestic and foreign counterparts, for innovation-driven and comprehensive utilization of resources. It will make new greater contributions for efficient, clean and low-carbon utilization of global petrochemical energy.
Thanks for your advices