Enhanced Coalbed Methane (ECBM)
Field Test at South Qinshui Basin, Shanxi Province, China

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ECBM Project in China

Micro Pilot
to Pilot
to Commercial Demonstration
Micro-Pilot Test Goals

- To measure and evaluate data to obtain estimates of reservoir properties and sorption behavior
- To calibrate a simulation model for estimation of the enhancement of CBM recovery in a larger-scale pilot or full field development

Enhancement of CBM recovery can not be estimated directly from micro-pilot test data
Demonstration Site Location

Shanxi Province
- Taiyuan
- Qinshui Basin
- Qinshui County
- Jincheng

Hebei Province
- Shijiazhuang

Henan Province
- Anyang
- Changzhi
- Zhengzhou

Potential Pilot Area
- Qinshui Basin
- Hebei Province
- Henan Province
Attractiveness of Qinshui Basin

- Large areal extent
- Thick, laterally continuous coal seams
- Highest gas contents measured in China
- Relatively shallow depths of coal seams
- Reasonable access to local and distant markets (West to East Pipeline is 30-90 km from south Qinhsui at Jincheng)
- Relatively more explored than other basins
Coal Characteristics

- Qinshui Basin: 24,000 km²
  - CBM Resource: 5.5 trillion sm³
- Primary CBM recovery performance in South Qinshui Basin (CUCBM owned 20+ wells)
  - Peak rate: 5,000 – 16,000 sm³/d
- High rank semi-Anthracite and Anthracite coal
  - Vitrinite reflectance: 2.7 – 4%
China ECBM Project

Canadian International Development Agency (CIDA)

Ministry of Commerce (MOFCOM)

Canadian Climate Change Development Fund (CCCDF) (CA $ 5 million)

China United Coalbed Methane Corporation Ltd. (CUCBM) (CA $ 5 million)

3.5 - year CA $ 10 million Project (Started March 2002)
Major Tasks

- Potential pilot site selection
- Geological/engineering/environmental characterization and ranking of selected 3 pilot sites
- Design of micro-pilot field test procedures to evaluate CBM reservoir properties
- Carry out a single well micro-pilot field test at the best suitable site
  - Selection of existing wells or drilling new wells
  - Up to three micro-pilot tests will be performed if first two tests do not show commercial potential
Major Tasks (Continued)

- Micro-pilot test evaluation and numerical model calibration and fine tuning
- Large-scale pilot design leading to commercial production
- Training and technology transfer to be conducted in Canada and China
Site Visit
Primary CBM Recovery Operation

CBM Production Well

Gas / Water Separator
Target Coal Seam Well for Field Test

- No. 3 seam – Shanxi Formation
  - Age: Carboniferous Permian coal
  - Depth: 478 meters
  - Average thickness: 6 meters
  - Reservoir temperature & pressure
    25C & 500 psi

- To isolate seam from lower No. 15 seam, a bridge plug set in TL003 well at 573 meters
Well Configuration

- Downhole gauges
- Perforated pup
- Nogo seating nipple
- Pump
- Wellhead
Downhole Gauge Installation

- Installed 2 sensors
  - 0 – 1500 psi range
  - 0.025% full scale accuracy
  - 0.0003% resolution
  - 120 C temperature
- Signals transmitted via multi-conductor electro-mechanical wireline cable
- Surface Readout
  - Live data readouts
  - 1M data points storage capacity

Gauge Carrier

Surface Readouts
On-line Gas Chromatograph

- Capable of measuring produced gas composition “on-line”
- Separates and quantitates: CO₂, CH₄, O₂, N₂, C₂-C₄, H₂S
- Analysis every 5 minutes initially & decreased to 1/hr as pilot continues
- Baseline Composition: CH₄ - 96.3%, CO₂ - 0.5%, N₂ - 3.67%, C₂ - 0.01%

Wang Guoqiang
TLOO3 Wellsite & Wellhead

Instrument Trailer

Well head with Downhole gauge packoff
**CO₂ Injection Strategy**

- Goal is to inject 200 tonnes into reservoir over a 12 day period. Each truck can transport 18 tonnes of CO₂.
- Injection rate to be maintained below reservoir fracture pressure (1100 psi).
- Estimate average injection rate of 30L/min over 8-10 hr period.
Injecting Liquid CO₂
Adsorption Isotherms

Qinshui Basin

Langmuir Selectivity = 1.2
Bottom-hole Pressure During Final Production Test

Cumulative Time (days)

Pressure (KPa)

CO2 Injection

Post CO2 Production Start

Pressure Buildup
Injectivity versus Cumulative CO$_2$
Gas Composition During Final Production Test

[Graph showing gas composition over time with CO2 and CH4 lines]
Results

- The average pressure of seam #3 is 1,241 kPa at a depth of 472 m
- Absolute permeability of the coal seam prior to CO₂ injection was 12 md, which was based on an effective permeability of gas of 2 md and a gas saturation of 40.8%
- 192 metric tonnes of CO₂ was injected
- Injectivity decreased during injection but permeability rebounded after an extended production period of 1 month
Summary

• The micro-pilot test as conducted in the South Qinshui TL-003 well has been completed successfully and has met all the technical objectives of the micro-pilot test.

• The history matching of the dataset from the micro-pilot and the simulation prediction for the multi-well pilot indicated a significant production enhancement compared to primary production, and that substantial CO$_2$ storage in the coal seam is feasible in a multi-well project.
5-Spot Field Pilot Test
Numerical Grid System

Region of Investigation:

Rectangular Grid:
35 × 35 × 3
(Seam #3, Water zone, Seam #15)

Grid Block Size:
20 m × 20 m
(except boundary grid blocks)
Design of 5-Spot Field Pilot Test
Numerical Simulation Scenario

- Continue after history matching run (November 19, 2003)
- Start CO₂ injection at new injector at a constant rate of 22,653 m³/d (0.8 MMscf/d)
  - Inject CO₂ at coal seam #3 only
- Continuous production at all four Wells FZ-002, FZ-003, FZ-008 and TL-003 at 1,560, 2,400, 1,400 and 1,450 kPa, respectively)
ARC Permeability Theory
Fracture Porosity used in Reservoir Simulation

Initial Conditions: 97.54% CH$_4$, 2.54% N$_2$, 0.04% CO$_2$

$\phi_{atm} = 0.00822 \Rightarrow \phi_i = 0.008$
**ARC Permeability Theory**

**Fracture Permeability used in Reservoir Simulation**

Initial Conditions: 97.54% CH₄, 2.54% N₂, 0.04% CO₂

\[ k_{atm} = 13.67 \text{ md} \Rightarrow k_i = 12.6 \text{ md} \]
5-Spot Field Pilot Test

CO$_2$ Injection

Time 0 = March 16, 1998

Start CO$_2$ Injection (5.6783 years)

Below estimated coalbed fracture pressure
5-Spot Field Pilot Test

Methane Production Rate

Time 0 = March 16, 1998

Start CO₂ Injection

After 6 months CO₂ Injection

FZ-002
FZ-003
FZ-008
TL-003

Thick Curves: CO₂-ECBM
Thin Curves: Primary CBM
5-Spot Field Pilot Test
CO₂ Distribution in Coal Seam #3

FZ-008  TL-003
FZ-002  FZ-003

6 months  1 year  2 years
3 years  4 years  5 years

CO₂ Mol Fr. in Fracture

1.0  0.9  0.8  0.7  0.6  0.5  0.4  0.3  0.2  0.1  0.0
5-Spot Field Pilot Test

**CO₂ Inventory**

Time 0 = March 16, 1998

- Start CO₂ Injection (5.6783 years)
- After 6 months CO₂ Injection
- CO₂ Stored

Start CO₂ Injection (5.6783 years)
## 5-Spot Field Pilot Test

### Performance Prediction

<table>
<thead>
<tr>
<th>Well</th>
<th>FZ-002</th>
<th>FZ-003</th>
<th>FZ-008</th>
<th>TL-003</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂ Breakthrough Time</strong>*&lt;br&gt;(year after CO₂ injection)</td>
<td>2.6822</td>
<td>5.1233</td>
<td>3.8274</td>
<td>3.1205</td>
</tr>
<tr>
<td><strong>Average CH₄ Production Rate</strong>&lt;br&gt;before CO₂ breakthrough&lt;br&gt;(m³/day)</td>
<td>5,275</td>
<td>3,600</td>
<td>4,657</td>
<td>1,394</td>
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<tr>
<td></td>
<td>1,883</td>
<td>240</td>
<td>718</td>
<td>405</td>
</tr>
<tr>
<td><strong>Peak CH₄ Production Rate</strong>&lt;br&gt;before CO₂ breakthrough&lt;br&gt;(m³/day)</td>
<td>6,319</td>
<td>4,901</td>
<td>5,355</td>
<td>1,789</td>
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<td></td>
<td>2,036</td>
<td>627</td>
<td>1,305</td>
<td>520</td>
</tr>
<tr>
<td><strong>Enhancement Factor</strong>**</td>
<td>2.80</td>
<td>15.00</td>
<td>6.49</td>
<td>3.44</td>
</tr>
</tbody>
</table>

* Time after CO₂ injection when 10% CO₂ occurred in production gas stream

** Ratio of average CH₄ production rate: (CO₂-ECBM) / (Primary CBM)
5-Spot Field Pilot Test
Cumulative CBM Production
5-Spot Field Pilot Test

Recommendation

- 20-acre 5-spot field pilot:
  - Four corner producers are existing CBM Wells FZ-002, FZ-003, FZ-008 and TL-003
  - Drill one new injector located approximately at the center of the pattern

- Inject CO$_2$ continuously at new injector at a constant rate of 22,653 m$^3$/d (0.8 MMscf/d) for 6 months
  - Enhancement of CH$_4$ production should be observed at all producers even though no CO$_2$ breakthrough should be observed at all producers