GHGT-11

Description of a CO₂ enhanced coal bed methane field trial using a multi-lateral horizontal well

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Abstract

Enhanced recovery of coal bed methane by CO₂ injection (CO₂-ECBM) offers the potential of increasing recovery of the gas in place over primary recovery methods and at the same time storing CO₂. This paper describes a CO₂-ECBM field trial using a multi-lateral horizontal well for injection. The trial, performed in China’s Ordos basin, involved transport of liquid CO₂ to the injection site and pumping of this directly into the injection well. A u-tube sampling system was installed in a monitoring well approximately 20m from the main horizontal branch close to the vertical section of the injection well. This u-tube system comprised three intervals separated by inflatable packers from which gas and water samples were automatically collected and recovered to an on-site field laboratory for gas analysis. The middle interval of this packer assembly sampled the target coal seam. At the start of injection a pulse of a non-adsorbing tracer gas was added to the CO₂. There was clear breakthrough of the tracer in the middle packer interval of the monitoring well demonstrating the good connection between injection and monitoring wells. The CO₂ composition of the gas sample from the coal seam gradually increased over time as injected CO₂ migrated to the monitoring well. Some significant aspects of this trial are the use of a multi-lateral horizontal well for ECBM, tracer gas in coal bed methane, the monitoring of gas displacement during ECBM and the u-tube sampling system.

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Selection and/or peer-review under responsibility of GHGT

Keywords: ECBM; CO₂ storage; coal bed methane; tracer gases

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1. Introduction

Coal bed methane (CBM), also known as coal seam gas, is a term used to refer to gas stored within coal seams and is a growing source of natural gas. Australia could have 200 Tcf (trillion cubic feet) of coal bed gas resources [1]; for comparison, in 2011 Australia’s gas production was just under 2 Tcf [2]. Coal bed methane is well positioned to play an important role in meeting the energy needs not only for Australia but throughout the region through export of liquefied natural gas (LNG). China also has a significant coal bed methane resource which has been estimated at between 1071-1250 Tcf or roughly 1000 years of current consumption [3].

Enhanced coal bed methane (ECBM) involves the injection of CO₂ into the reservoir with the aim of displacing the reservoir methane. The main perceived benefits from CO₂-ECBM are the enhanced recovery of coal bed methane and the storage of CO₂. The degree of enhancement over conventional primary recovery is a complex function of a range of reservoir and operational conditions, and so will be largely site specific. However an analysis of the Allison Unit trial in the San Juan basin estimated the potential recovery with ECBM at up to 95% of the gas in place compared with 77% without enhanced recovery [4]. For Australia, this improved recovery yield could represent approximately an additional 36 Tcf, based on the CBM resource estimates presented above; or, in other terms, a further 51 years of Australia’s east coast consumption at 2006 rates [5]. When this enhanced recovery is combined with a price on carbon, ECBM may be an attractive amendment to existing coal bed methane operations, particularly where there is on-site generation of electricity which would provide a ready CO₂ source.

Coal has approximately twice the adsorption capacity for CO₂ than for methane; however, coal swells with gas adsorption and the swelling is a direct function of the quantity of gas adsorbed. This swelling acts to reduce the coal porosity and thus the permeability and in the various field trials this has led to reduced rates of CO₂ injection [4, 6, 7]. Since coal permeability is typically relatively low, a key challenge to the success of CO₂-ECBM is the optimal management of coal swelling with CO₂ injection.

Another important challenge for CO₂-ECBM is the management of the breakthrough of injected CO₂ in the produced methane. This is contingent on a sound understanding of the gas migration process within the reservoir. A set of tools is required to characterise the gas migration process so that the CO₂-ECBM operation can be planned with confidence.

The only way to establish the technical feasibility of CO₂-ECBM is through field trials. This paper describes a field trial of CO₂-ECBM at a site in Shanxi Province, China. The trial involved collaboration between CSIRO and China United Coal Bed Methane Corp (CUBCM), with financial support from the Australian Federal Government under the Asia Pacific Partnership for Clean Development and Climate, CSIRO’s Advanced Coal Technology Portfolio, Chinese Government and CUBCM.

This trial used a number of novel technologies for CO₂-ECBM; one of these was a multi-lateral horizontal well for CO₂ injection. This advanced type of well maximises the contact area with the target formation and could act to alleviate the effects of any decline in permeability due to coal swelling with CO₂ adsorption. The project also involved a number of novel monitoring technologies for CO₂-ECBM, the key aspect of which was a dedicated monitoring well with a u-tube system. A version of the u-tube sampling system originally described by Freifeld et al. [8, 9] was used in this project. This automated apparatus allowed reservoir gas to be sampled and retrieved for analysis in an on-site field laboratory. The gas sampling system also sampled formations above and below the target formation for storage assurance. The project also used a tracer gas in a novel development for ECBM. This identified the flow pathways and rates within the reservoirs and provided data on storage assurance.

2. Field Site
Figure 1 presents a map showing the location of the APP ECBM site in Liulin County, Shanxi Province. Liulin is about 200 km from Taiyuan City, the capital of Shanxi Province and about 700 km from Beijing.

At the field site an existing multi-lateral horizontal well, which had been in gas production for approximately 12 months, was converted for injection. This type of well has a number of horizontal branches which connect to a central trunk. A separate vertical well connects to the central trunk and is used for gas production and injection.

The well trajectory for the horizontal well from the well survey is presented in Figure 2 with the location of the middle interval of the monitoring well also indicated. These branches were drilled to follow the dip of the coal seam.

Table 1 presents the lithology at the site as determined from the geological log during drilling of the monitoring well; the coal seams #3 and #4 were targeted for CO₂ injection.
Figure 2. The trajectory of the injection well’s branches (coloured lines) and the location of the second interval in the monitoring well in the target reservoir.

Table 1. Overview of the site geology.

<table>
<thead>
<tr>
<th>System</th>
<th>Group</th>
<th>Bottom boundary depth (m)</th>
<th>Thickness (m)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Quaternary</td>
<td></td>
<td></td>
<td></td>
<td>Pale yellow loess layer</td>
</tr>
<tr>
<td>Two Stack System</td>
<td>Stone Box</td>
<td></td>
<td></td>
<td>Mainly purple, gray mudstone, gray fine sandstone, gray sandstone, gray sandstone.</td>
</tr>
<tr>
<td></td>
<td>Xiashihezi</td>
<td>96.0</td>
<td></td>
<td>Gray mudstone and gray sandstone, gray in sandstone.</td>
</tr>
<tr>
<td></td>
<td>Shanxi Group</td>
<td>581.0</td>
<td>77.0</td>
<td>Main coal-bearing strata, composed of fine gray sandstone, sandstone, dark gray, silty mudstone, fine sandstone, gray mudstone, siltstone and coal #3 &amp; #4 coal seams: 560.77 ~ 565.47m, thickness 4.70m #5 coal seam: 567.60 ~ 572.47m, thickness 4.87m</td>
</tr>
<tr>
<td>Stone Carbon System</td>
<td></td>
<td>684.0</td>
<td>103.0</td>
<td>This group is another coal-bearing strata; comprising gray mudstone, siltstone, silty mudstone, dark gray limestone, sandy mudstone and fine sandstone, sandstone and coal. #8 +#9 coal seam. #9 #8 coal: 621.97 ~ 631.77m, thickness 9.80m</td>
</tr>
</tbody>
</table>
3. Monitoring and Injection Equipment

The monitoring equipment used in the trial is described in Table 2.

Table 2. Equipment used in the trial.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
</table>
| Injection well            | Pressure and temperature transducers located at top (1x) and bottomhole (2x for redundancy)  
                          | CO₂ injection rate and temperature                                           |
                          | Tracer injection loop                                                       |
                          | Diesel powered CO₂ booster pump                                             |
| Monitoring well           | Downhole assembly for u-tube system – three depth intervals                  |
                          | Downhole pressure and temperature                                           |
| Field laboratory          | Automated system for operating u-tube and gas analysis                       |
                          | N₂ membrane system for u-tube drive gas                                     |
                          | Data acquisition, control and remote communication                           |
| Site power                | Generator and back-up generator                                             |
| Operators accommodation   | On-site housing for operators                                               |
The monitoring well was perforated so that the coal seam that is the injection target was the middle monitoring interval. Perforations were also placed above the coal seam and below so that potential migration of CO₂ outside of the target coal seam could be monitored. The perforations and installation of monitoring equipment were performed on 11-12/09/2011.

The u-tube system allowed samples of reservoir fluids to be collected and recovered to surface. The downhole assembly of the u-tube largely followed the Freifeld et al. [8, 9] approach. However the handling of the recovered fluid sample differed significantly from that of Freifeld et al., who, in order to preserve water chemistry, maintained pressure in the sampling system. In the system used in this project, the focus was gas analysis and water solution chemistry was not monitored. This simplified the sample handling system with the fluid sample depressurized at surface, gas and water separated, and the water disposed.

To recover a sample of reservoir gas and water with this system, the u-tube is first purged with high pressure nitrogen. While the u-tube pressure is above reservoir pressure, a downhole check valve between the u-tube and reservoir is closed and any gas or water in the u-tube is pushed to the surface laboratory. In the laboratory the fluid enters a gas-water separator which has a pressure relief valve that opens at 300 kPa, disposing excess gas to a vent line. A gas sample is automatically taken from the head space of the gas-water separator and flows to the gas chromatograph for composition analysis. At the end of the purge cycle the nitrogen purge gas supply is shut-off, the mass of water in the separator is measured and then the water is disposed of. At this point the u-tube is full of nitrogen gas at the drive pressure. Then u-tube pressure is allowed to blow-down by venting to atmospheric pressure. When the u-tube pressure is less than the reservoir pressure, the downhole check valve between u-tube and reservoir opens and reservoir fluid flows into the u-tube. After a user set blow down time the vent valve is closed and reservoir fluid inflow continues until the u-tube pressure equilibrates with the reservoir pressure.

The three monitoring intervals were isolated by four inflatable packers which were installed using a winch operated wireline system. Downhole vibrating wire pressure transducers were also attached to the u-tubes to measure the pressure within each packer interval.

4. Observations of CO₂-ECBM

4.1. Injection Well Data

The CO₂ was sourced from a commercial gas supply company located at the city of Changzhi, approximately 500km from the site. The CO₂ was transported by tanker truck in liquid form to the field site where it was pumped into the injection well using the booster pump via the flow skid. Injection commenced on the 15/09/2011 and in total there were 58 tanker deliveries to the site, however, site access was frequently disrupted by weather conditions, roadwork and/or traffic congestion. In total 460 tonnes of CO₂ were injected during the trial; Figure 3 presents a graph of the cumulative quantity injected with time and the rates for each injection.
4.2. Monitoring Well Observations

Figure 4 presents the CO₂ concentration of the reservoir gas recovered from the middle monitoring interval of the u-tube system with time. Also presented in Figure 4 is the tracer gas concentration with time; the tracer gas used in this work was sulphur hexafluoride (SF₆) which has a minimal background, very low detection limits (via GC ECD), and is low or non-absorbing for coals. Two pulses (~ 2 kg each) of SF₆ were injected; the first at the start of CO₂ injection, the second towards the end. There was rapid breakthrough of this tracer at the monitoring well demonstrating the good connection between injection and monitoring wells. While the tracer gas broke through quickly, the CO₂ concentration increased gradually during the project demonstrating that, despite being only 24m distant in the reservoir, CO₂ migration was gradual.
5. Conclusions

In total over 460 tonnes of CO$_2$ were injected during the trial. An excellent set of unique observations of the ECBM process was obtained. Of particular note was the gradual breakthrough of CO$_2$ at the monitoring well where the concentration of CO$_2$ in the free methane within the reservoir increased to approximately 15% by the end of injection. The presence of free methane during CO$_2$ injection reflected the displacement of the reservoir gas by the injected CO$_2$. These unique observations demonstrate the process of enhanced recovery of coal bed methane and show that CO$_2$ breakthrough did not occur in a premature fashion but was progressive.

An important challenge for CO$_2$-ECBM is permeability decline due to coal swelling with CO$_2$ adsorption. Significant decline in permeability would be exhibited by decreases in the rates of CO$_2$ injection. The observed injection behaviour during the trial is still being interpreted as there are several complications regarding the flow process within the horizontal well. These complications relate to the potential for coal fines accumulation and possible loss of sections of the injection well due to wellbore collapse. This last issue could be overcome in future projects of this nature by using a cased or lined horizontal well.

This innovative project has involved a number of novel technologies, such as the injection of CO$_2$ using a multi-lateral horizontal well and the monitoring of the enhanced displacement of reservoir methane and storage of CO$_2$. It showed that, for this reservoir, there was a progressive sweep of methane by the injected CO$_2$ and that early breakthrough of CO$_2$ did not occur. In addition, the injected CO$_2$, free methane and tracer were only observed within the target reservoir and not in the neighbouring formations.

Figure 4. Gas analysis from the middle monitoring interval of the u-tube system; CO$_2$ concentration in reservoir gas with time compared with the CO$_2$ injection (left) and tracer gas concentration (SF$_6$) with time (right).
providing evidence of storage assurance. While the benefits of a multi-lateral horizontal well are clear for production or injection for low permeability formations, the results from this project suggest that such wells need to be cased or lined for soft, fragile formations such as coal.

6. References


