Field experiment of Japan CO$_2$ geosequestration in coal seams project (JCOP)

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Abstract
The Japanese Ministry of Economy, Trade and Industry began, in 2002, a six-years project on CO$_2$ sequestration in coal seams entitled as “Japan CO$_2$ Geosequestration in Coal Seams Project (JCOP)” as one part of the “Carbon Dioxide Sequestration and Effective Use Program”. The purpose of this project is to develop a series of processes that can 1) extract the CO$_2$ discharged from thermal power plants and other large-scale emitters, 2) fix it within coal seams in a stable state, and 3) in the process, recover methane as a clean energy source.

This project involves field tests in the Ishikari coal field, Hokkaido in Japan. Two wells were drilled in 2003 and 2004, and a CO$_2$ sequestration field experiment was conducted for the first time in Japan in 2004. A larger volume of CO$_2$ was injected in 2005. This paper introduces these field experiments and shows analyzed results obtained through the numerical modelling of the experiments.

Keywords: CO$_2$ sequestration, coal seams, field experiment, numerical modelling

Introduction
CO$_2$ geosequestration is known as one of innovative technologies to reduce the greenhouse gas emissions in the atmosphere. CO$_2$ geosequestration process includes several methods such as sequestration of CO$_2$ into oil and gas reservoirs, aquifers, or coal seams. Among of these methods, CO$_2$ sequestration utilizing coal seams is considered to be more advantageous in the following points: 1) CO$_2$ is adsorbed on coal seam and fixed firmly, 2) methane gas produced as a by-product [1].

The Japanese Ministry of Economy, Trade and Industry began, in 2002, a six-years project on CO$_2$ sequestration in coal seams entitled as “Japan CO$_2$ Geosequestration in Coal Seams Project (JCOP)” as one part of the “Carbon Dioxide Sequestration and Effective Use Program”. This project involves fundamental research into CH$_4$-CO$_2$-coal interaction, CO$_2$ monitoring technologies, cost reduction of CO$_2$ capture from flue gases, and the economics of sequestration [2]. This project also involves preliminary field experiments, which have been conducted in the Ishikari coal field since 2003. Two wells were drilled in 2003 and 2004, and the first CO$_2$ sequestration experiment utilizing coal seams was conducted in 2004. A larger volume of CO$_2$ was injected in 2005.
paper introduces these field experiments and shows analyzed results obtained through the numerical modelling of the experiments.

**Field Experiment**

In 2004, after drilling of PW-1, setting up CO$_2$ injection facilities, and performing some preliminary production and CO$_2$ injection tests, a multi well test with IW-1, which was drilled in 2003, and PW-1 commenced in October. CO$_2$ was injected at IW-1 by controlling the bottom hole injection pressure at 15.0 MPa, which was slightly lower than the cleat opening pressure, and coalbed methane gas was produced from PW-1. The cleat opening pressure was estimated as 15.8 MPa from water injection falloff test in 2003. This is the first test of CO$_2$ sequestration in Japanese coal seams. Figure 1 shows CO$_2$ injection performance at IW-1 during the injection period. A total of 35.7 metric tons of CO$_2$ was injected at an average rate of roughly 2.3 metric tons per day. It should be noted that it was possible to inject CO$_2$ at a constant rate during the injection period, although the CO$_2$ injection rate was much lower than expected. Well damage due to fine coal particles was strongly suspected.

![Figure 1 CO$_2$ injection performance at IW-1 of a multi well test in 2004](image)

In 2005, after a preliminary test of full wave tomography for the investigation of possibility to monitor the movement of injected CO$_2$, a multi well test with IW-1 and PW-1 commenced in August. CO$_2$ was injected at IW-1 and coalbed methane gas was produced from PW-1. Figure 2 shows CO$_2$ injection performance at IW-1 during the injection period. CO$_2$ was injected by controlling the bottom hole pressure at 15.5 MPa. A total of 115.4 metric tons of CO$_2$ was injected. The initial CO$_2$ injection rate was 1.6 metric tons per day, which was a little lower than that at the test in 2004. It should be noted that the injection rate increased constantly as the injection continued. The last injection rate was 3.5 metric tons per day, which was almost double the volume of the initial injection rate. This may be due to the decrease of effective stress at the coal seam surrounding IW-1, which opened the cleats in coal. Figure 3 shows gas and water production performance at PW-1 during the multi well test. Gas production from PW-1 increased after the CO$_2$ injection started at IW-1, and began to decrease right after the end of CO$_2$ injection. This clearly shows that the CO$_2$ injection at IW-1 affected on the coalbed methane gas production at PW-1. This result may also indicate the CO$_2$/CH$_4$ exchange mechanism actually happened in a real coal field.

In 2006, it is scheduled to conduct longer-term multi well field experiment after N$_2$ injection at IW-1 for the improvement of injectivity.
Some injection falloff or build-up tests at IW-1 were conducted and analyzed during the field experiments to investigate permeability change at the CO₂ injection well. Table 1 summarizes analyzed results of well tests at PW-1. Coal seam absolute permeability was estimated as 1 md before CO₂ injection. It reduces to 0.08 md after the first preliminary CO₂ injection in Nov. 2004. Then the injection and production wells were shut in during winter. The analyzed result of injection falloff test in May, 2005 indicated the permeability was reduced to 0.01 md during the shut-in period. We are not sure the accuracy of these well test results, however, these results might indicate the coal seam permeability reduction due to coal swelling induced by CO₂ adsorption on coal as reported by other field experiment [3], [4].
Table 1  Summary of well tests conducted at CO\(_2\) injection well during multi well tests

<table>
<thead>
<tr>
<th>Type of Well Test</th>
<th>Date</th>
<th>Absolute Permeability (md)</th>
<th>Skin Factor</th>
<th>Radius of Investigation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Injection Falloff Test</td>
<td>Nov. 2003</td>
<td>1.07</td>
<td>0.95</td>
<td>52</td>
</tr>
<tr>
<td>Build-up Test</td>
<td>Sep. 2004</td>
<td>0.08</td>
<td>4.2</td>
<td>21</td>
</tr>
<tr>
<td>CO(_2) Injection Falloff Test</td>
<td>Nov. 2004</td>
<td>0.08</td>
<td>1.3</td>
<td>59</td>
</tr>
<tr>
<td>Water Injection Falloff Test</td>
<td>May 2005</td>
<td>0.01</td>
<td>2.74</td>
<td>8</td>
</tr>
</tbody>
</table>

Numerical Modelling

The Ishikari model was constructed to perform numerical simulations for CO\(_2\) sequestration field tests conducted in the Ishikari coal filed [2]. The main purpose of the simulations is to help design the field tests. The model is also utilized to analyze field test results, and moreover the model may be used to estimate future CO\(_2\) sequestration test performance as well as sequestrated CO\(_2\) volume. The initial Ishikari model was constructed based on geological information, coal seam properties obtained by field well tests, in-situ and laboratory measurements. However, for some properties such as sorption time, porosity, pore volume compressibility and relative permeability curve, hypothetical values were used. History matching studies on the multi well test in 2004 were performed to estimate these unknown properties and construct the improved Ishikari model [5].

For the history matching studies, CO\(_2\) injection rate at IW-1 and water production rate at PW-1 were used as input to match gas production rate at PW-1. Sensitivity studies for unknown coal seam properties were performed until obtaining good match between calculated and measured gas production at PW-1. A combination of matching parameters shown in Table 2 gave the best history matching result for gas production rate at PW-1, as presented in Figure 4. Through history matching studies, it was indicated that linear relative permeability curve was appropriate for gas and water multiphase flow through coal cleats. It was also clarified that the reduction tendency of gas production rate after reaching peak gas production depended on coal compaction. In this history matched case, the improved Ishikari model estimated that 98% of injected CO\(_2\) was adsorbed on coal and sequestrated. The improved Ishikari model was also validated against the multi well test in 2005. The same model was used to compare calculated and measured production data and good matching was obtained as shown in Figure 5.

Figure 6 compares measured and calculated CO\(_2\) injection rate as a function of absolute permeability for the grid of IW-1. This figure also indicates that absolute permeability reduced at the coal seam surrounding CO\(_2\) injection well during CO\(_2\) sequestration experiment.

Table 2  History matching parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Estimated Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Permeability Curve</td>
<td>Linear</td>
</tr>
<tr>
<td>Sorption Time (day)</td>
<td>5.0 (CH(_4)), 2.5 (CO(_2))</td>
</tr>
<tr>
<td>Cleat Porosity (%)</td>
<td>0.8</td>
</tr>
<tr>
<td>Pore Volume Compressibility (1/kPa)</td>
<td>1.0 x 10(^{-4})</td>
</tr>
</tbody>
</table>
Figure 4  History matching for gas production rate at PW-1 of a multi well test in 2004

Figure 5  History matching for production data at PW-1 of a multi well test in 2005

Figure 6  Comparison of measured and calculated CO$_2$ injection rate as a function of absolute permeability for the grid of IW-1
Conclusions
The CO$_2$ sequestration project entitled “Japan CO$_2$ Geosequestration in Coal Seams Project (JCOP)” commenced in 2002 as one part of the “Carbon Dioxide Sequestration and Effective Use Program”, promoted by the Japanese Ministry of Economy, Trade and Industry (METI). In 2004, CO$_2$ was actually injected and sequestrated in coal seams for the first time in Japan. A larger volume of CO$_2$ was injected in 2005. By analyzing these multi well field test results, it is indicated that the CO$_2$/CH$_4$ exchange mechanism actually happened in a real coal field. The Ishikari model was constructed and improved through history matching studies of the multi well tests in 2004 and 2005. By history matching studies, unknown coal seam properties such as relative permeability, CH$_4$ and CO$_2$ sorption time, cleat porosity of coal seam, and pore volume compressibility were estimated. Through well test analyzed results at IW-1 and numerical modeling studies, it was indicated that absolute permeability at the coal seam surrounding CO$_2$ injection well reduced due to coal swelling induced by CO$_2$ adsorption on coal.

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List of References