Reservoir evaluation for the T1 Member of the Takinoue Formation at Tomakomai candidate site for CCS demonstration project in Japan

Tatsuhiko Matsuuraa, Jun Mikamia, Daisuke Itoa, Mitsuru Kamona, Takuya Maeda, Satoru Tomita, Takao Inamoris, Naoshi Aokis, Arata Katoha, Kohei Akaku, Shinjiro Kuroki, Yoshinori Yamanouchic

aJapan Petroleum Exploration Co., Ltd. Tokyo 100-0005 Japan
bJGI, Inc. Tokyo 112-0012 Japan
cJapan CCS Co., Ltd. Tokyo 100-0005 Japan

Abstract

This paper summarizes the results of a reservoir evaluation study for the T1 Member of the Takinoue Formation at Tomakomai candidate site for CCS demonstration project in Japan. The Takinoue Formation is modeled with 3D seismic and well data and total of fifty realizations are made by geostatistical method. CO2 injection is simulated with the realizations and it is confirmed that 250,000 ton/year of CO2 can be injected through 3 years injection period and be stored for 1000 years.

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Keywords: CO2 storage; volcanic rock; geostatistical method; simulation

Introduction

Carbon Dioxide Capture and Storage (CCS) is a key technology to reduce carbon dioxide emission to the atmosphere and needed to be widely deployed in the world as early as possible. A number of demonstration CCS projects are started in many areas. As in Japan, the Ministry of Economy, Trade and Industry (METI) started the CCS Demonstration Project in 2008.

Possible candidate storage sites were evaluated based on the storage potential [1]. Criteria applied for screening of candidate site are 1: storage potential of reservoir and seal, 2: presence of nearby CO2.
sources to be injected, 3: applicability of capture technology and 4: issues to be demonstrated through the project. Among the criteria, the most important one is storage potential.

Tomakomai candidate site, one of the candidates, is located in Hokkaido Prefecture, northern Japan. CO₂ is planned to be captured at the existing hydrogen plants and injected into saline aquifers subsea bed through inclined wells to be drilled from the seaside. The planned amount of CO₂ is between 100,000 and 250,000 tons / year for 3 years. Since there are petroleum exploration activities around the candidate site, there are some geological and geophysical data available for the site evaluation.

This study area is located in the uplift zone of Mesozoic igneous basement called “Tomakomai Ridge”. The Neogene section consists of the Takinoue, Fureoi, Biratori-Karumai and Nina formations, overlaid by the Quarternary the Moebetsu and Mukawa formations. An anticline, called “Tomakomai-Oki Structure”, runs with NNW-SSE axis through the study area.

Prior to the study, shallow marine 3D seismic surveys were conducted and two survey wells were drilled to take wire-line and core data. Using all available geological and geophysical data, the Takinoue and Moebetsu formations of this candidate site were evaluated to be suitable for CCS demonstration. This paper reports the study for the T1 Member of the Takinoue Formation.

Fig. 1 Location map for Tomakomai CCS candidate site
2. Geological Interpretation

2.1 Seismic Interpretation

Prior to the study, shallow marine 3D seismic surveys were conducted over 4 km x 4 km area in 2009, and over 6 km x 8 km in 2010. Also a survey well was drilled in 2010 to acquire wire-line and core data. For the interpretation, the following data were used:

- Combined 3D seismic processed data in 2009 and 2010
- Data of survey wells drilled in 2010 and 2011
- Other seismic data obtained by petroleum exploration company
- Other well data drilled by petroleum exploration company

The Takinoue Formation consists of the lower mudstone and the upper volcano-clastic members. The latter is called the “T1 Member” and is a good reservoir of the oil fields of the neighborhood. The T1 Member is overlaid by thick mudstone of the Fureoi and Biratori-Karumai Formations which are considered to be a good cap rock. The T1 Member is further divided into two parts, upper part is predominated by tuff and lower part is predominated by lava and tuff breccia. According to the existing well data, lava and tuff breccia tend to have higher permeability than tuff.

From the interpretation of 3D seismic data, it is confirmed that coarse sediments of the T1 Member, which is expected to have high porosity and permeability, are widely spread continuously on the NNS-SSE trending anticline structure. Also, the data reveal that a high-angle reverse fault runs at the west wing of the anticline. Because the fault cuts only formations deeper than the Nina Formation, we evaluated that the activity of the fault terminated in Pliocene, during the depositional age of the Nina Formation.
2.2 Facies Analysis
Since the lithology of the Takinoue Formation is volcanics, it is more heterogeneous than sandstone formation. It is crucial to evaluate the spatial distribution of facies and properties.

At first, skeleton attributes are extracted from the 3D seismic migration data. Based on the skeleton attributes, Self-Organizing Map (SOM) is made, and then K-means analysis was made to divide into 10 K-means Index. To find the target zone in the T1 Member, facies are divided into two categories, lava / tuff breccia and tuff by comparison between well data and K-means Index volume.

2.3 Property Modeling
For CO₂ injection simulation, reservoir properties are distributed to the model.

In the T1 Member, by using geostatistical method with 3D seismic and well data, fifty realizations are made. Fig. 3 shows the work flow for the property modeling.

Facies model in 3D seismic data are made (Facies-1) by K-means Index volume. Porosity (\( \phi \)) is modeled with the acoustic impedance (AI) volume from AI / porosity relationships in all facies from Well A and CCS-1 data. At the same time, porosity at well A and CCS-1 are evaluated from density log to construct hard data (\( \phi \)) . Next, facies distribution for study area (facies-4) is made by Sequential Indicator Simulation (SIS) with facies-1 as hard data. Based on Facies-4, porosity (\( \phi \)) is distributed over the area by Sequential Gaussian Simulation (SGS) using \( \phi \). Porosity distributions for each realization (\( \phi \)) are made by SGS using Facies-4 as category data, \( \phi \) as soft data and \( \phi \) as hard data. Permeability distribution (k-7) is made from relationships between porosity and permeability in each facies at Well A and CCS-1.

Properties for the other formations are evaluated from core samples and logs of the Fureoi Formation in Well A.

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**Fig.3 Work Flow for geological modeling**

3. Reservoir simulation for CO₂ injection
3.1 Overview of simulation model

Based on the geological model, reservoir simulation for CO$_2$ injection is conducted by using GEM (ver2010.12), Computer Modelling Group Ltd.. In the simulation, structural & stratigraphic, residual and solubility trappings are considered.

Inclined injection well is designed to drill from seaside, and the target zone is set to entire the T1 Member. From the survey well data, leak-off pressure at the bottom of the Fureoi Formation is 1.96 of EMW. The fracturing pressure at the top of the reservoir, 2,419.4mVD, is calculated and the maximum injection pressure is set to 90% of the fracturing pressure. The injection volume is set to 250,000 tons / year x 3 years.

Table 1 shows the simulation parameters. Some parameters are taken from the survey well data and others are from literatures.

Table 1 Parameters for T1 Member CO$_2$ injection simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>8km x 12km x 4000m</td>
</tr>
<tr>
<td>Grid</td>
<td>80 x 120 x 106</td>
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<tr>
<td>Active Grid</td>
<td>384,050</td>
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<tr>
<td>Datum Temperature</td>
<td>91.0 °C (2,419.4m)</td>
</tr>
<tr>
<td>Datum Pressure</td>
<td>34,376kPa (2,419.4m)</td>
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<tr>
<td>Injection rate</td>
<td>250,000 tonne/year x 3 years</td>
</tr>
<tr>
<td>Maximum Injection Pressure</td>
<td>41,853kPa</td>
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<tr>
<td>Facies</td>
<td>Lava</td>
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<tr>
<td>Average porosity</td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td>0.127</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
</tr>
<tr>
<td>average permeability (mD)</td>
<td>2.7</td>
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<tr>
<td></td>
<td>0.0017</td>
</tr>
<tr>
<td></td>
<td>0.000035</td>
</tr>
<tr>
<td>Compressibility (kPa$^{-1}$)</td>
<td>8.073 x 10$^{-11}$</td>
</tr>
<tr>
<td>Salinity (ppm NeCO$_2$)</td>
<td>35,100 (CF$^2$=21,300ppm)</td>
</tr>
<tr>
<td>Gas Relative Permeability</td>
<td>Bemnon[2]</td>
</tr>
<tr>
<td>Water Relative Permeability</td>
<td>Corey[3]</td>
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<td>Critical Gas Saturation</td>
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<tr>
<td>Irreducible Water Saturation</td>
<td>0.02[Bemnon[2]]</td>
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<td>Maximum Trapped Gas saturation</td>
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<td>Capillary Pressure Curve</td>
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<td>Experiment</td>
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<td>469</td>
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</table>

3.2 Simulation result

Three years injection is simulated for each realization and it is found that the designed injection are possible for all realizations. Realizations are ranked by the pressure increase after 3 years and the cumulative probability distribution is made. Fig.4 shows the cumulative distribution of pressure increase. Fig.4 also shows permeability distribution for each realization in the right hand side. From the amount of pressure increase, P10, P50 and P90 are chosen.

1) P10 model : Probability that the pressure increase is less than this model is 10%.
2) P50 model : Probability that the pressure increase is less than this model is 50%.
3) P90 model : Probability that the pressure increase is less than this model is 90%.

Fig.5 shows the injection performance for three cases. Even with P90 model, the injection pressure after three years is 37,660kPa and is much lower than the maximum injection pressure, 41,853kPa. It tells us that the 250,000 tons / year x 3 years injection is possible. For all three cases, reservoir pressure decreases rapidly, reaches near the initial reservoir pressure, 35,000kPa.
Fig. 4 Cumulative distribution of pressure increase of 50 realization

Fig. 5 Injection performance for P10, 50 and P90
Fig. 6 shows the pressure change after 3 years injection. The dark blue shows the little pressure increase and lighter blue shows the higher pressure increase. For all cases, the high pressure zone extends to N-S trend which coincide to anticline axis. The right hand side figures are the cross sections. On top of the light blue layer, there is dark blue layer which is the seal formation. In this seal formation, pressure change is very little, which indicates that it has enough seal capacity.

CO\textsubscript{2} is mainly injected to the upper part of the T1 Member which has better permeability. Gaseous CO\textsubscript{2} is distributed around the injection well and some amount of dissolved CO\textsubscript{2} is distributed beyond the supercritical CO\textsubscript{2}. After the injection, gaseous CO\textsubscript{2} remains at the same position and CO\textsubscript{2} saturation decreases by the dissolution. Formation brine which dissolve CO\textsubscript{2} becomes heavier and moves downwards.

Moveable CO\textsubscript{2} decreases rapidly after the injection and becomes almost 0 after 200 years. Trapped CO\textsubscript{2} by residual gas saturation dissolves into formation brine. After 1000 years, dissolved CO\textsubscript{2} becomes 45 to 70\% of total CO\textsubscript{2}, depending on the model. The difference of this amount is caused by difference of contact area caused by extension of CO\textsubscript{2} plume, movability of heavier brine which dissolve CO\textsubscript{2} and pressure distribution in the reservoir.

![Fig.6 Pressure change after injection](image)

4. **Conclusion**

As a possible CCS candidate, the Tomakomai site was evaluated by using data of newly acquired 3D seismic and well data, in addition with existing available data. The results are summarized as follows,

- The Takinoe Formation is divided into two members; upper T1 Member and lower Mudstone member. In this project, lava and tuff breccia of the T1 Member are expected to be CO\textsubscript{2} injection
target, and overlying mudstone of the Fureoi and Biratori-Karumai Formations are expected to be a cap rock.

- Through seismic interpretation, facies analysis and property modeling, total of fifty realizations are made by geostatistical method.
- To evaluate the CO₂ storage capacity and seal capacity, reservoir simulations were conducted. It was found that 250,000 tons / year x 3 years injection is possible and that CO₂ does not reach to seal formation for all cases even after 1000 years.
- The T1 Member of Takinoue Formation is appropriate for the CCS demonstration project.

Acknowledgements

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References