CO_2 Storage Research Group

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Research and Development on Geological CO_2 Storage for Safe CCS Operation

1. Introduction

In terms of capturing and sequestrating of CO_2 from large scale emission sources geological CO_2 storage is one of the most important options for achieving ambitious net zero CO_2 emission goals.

The CO_2 Storage Research Group as a member of the Geological Carbon Dioxide Storage Technology Research Association has conducted a project funded by the New Energy and Industrial Technology Development Organization (NEDO), called "Research and Development of CO_2 Storage Technology to implement safe CCS".

The project is in a technology development phase for large-scale CO_2 storage, which is qualified with safe injection and storage of more than 1 Mt CO_2/y under the ground. To achieve the goal, our group has been developing technologies for safety management, efficient injection and effective resource utilization for large scale CO_2 reservoirs.

Our development up to now has moved a number of technologies into a stage of demonstration in the fields: safety management systems for injection, assessment/monitoring technologies for the stability of geological formations and an efficient injection technology.

To contribute to large-scale CO_2 storage, it is critical to prove these technologies applicable for an actual site at scale. The CO_2 Storage Research Group has been working closely with universities and research institutes internationally to move forward with technical demonstration at large sites overseas.

Highlighted in the following sections are our outstanding achievements in 2020: a microbubble CO_2 injection technology, a safety management system for CO_2 storage (ATLS: Advanced Traffic Light System) and systems for CO_2 leakage detection and marine environmental impact assessment. We have developed these technologies as systems with high practicability and applicability. The microbubble CO_2 injection technology will be applied to multiple overseas geological CO_2 storage sites, including that in North Dakota, USA and that of the Junlun Petroleum Company in China.

Other technologies of ours being demonstrated at a CO_2 storage site include Distributed Fiber Optical Sensing (DFOS). We have created our own method to measure strains of geological formations and integrated it into multi-sensor systems capable of concurrent measurements of temperature, pressure, acoustic wave, and strain of geological formations. That system is also being implemented and demonstrated at an overseas site.

Through improving our technologies and implementing them in the fields, our group continues to contribute to CCUS deployment.

2. Major Research Topics and Outcomes

2.1. Microbubble CO_2 Injection technology

Microbubble CO_2 injection technology is to turn CO_2 into microbubbles through a special ceramic filter and then to inject the microbubble CO_2 under the ground. Microbubble CO_2 has the following advantages in injection for geological CO_2 storage:

- To easily enter gaps (pore throat) of sandstone that is composed of reservoir,
- To access more pore space than where CO_2 injected by a conventional way, and
- To easily dissolve in saline water.

The CO_2 Storage Research Group has demonstrated these advantages in lab and field tests. In the lab tests, we used core samples of rock in an X-ray CT scanner. The upper panel of Figure 1 shows a result from a series of tests. The panel illustrates CO_2 distribution at a time when CO_2 injected at the left edge reached a point 82mm away from the edge with warm color contour. The two core samples are comparable in terms of their pore space volume. Microbubble CO_2 fills the space more densely (upper panel of Figure 1) and is injected and dissolved more (lower panel) than conventionally-injected CO_2, so called normal bubble.

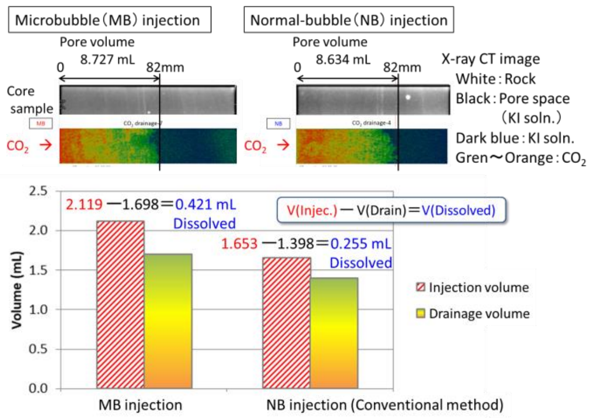

Fig. 1 Evaluation for storage efficiency of microbubble CO_2 using core samples

For the field tests of microbubble injection in 2020, we used the Sarukawa oil field owned by JAPEX in Oga, Akita, where we did previous tests last year. The targeted formation for injection there was a low permeable sandstone layer at a depth of around 800 m. In order to improve efficiency in installation of our microbubble CO_2 generator, we have designed a smaller system, length of which below the packer is 14 m, 1/6 in comparison with the last year one, 84 m (Figure 2). Thanks to the design change, time for installment and de-installment was reduced to about 1/3 from 15 hours to 4 hours.

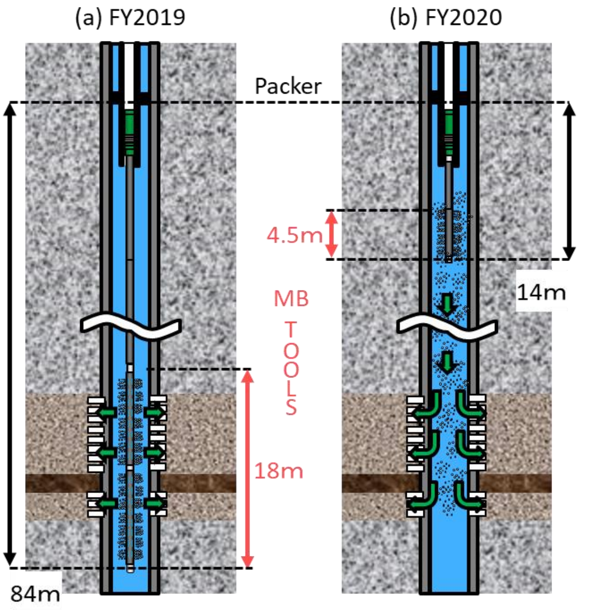

Fig. 2 Overview of the microbubble CO_2 injection tools settings in a borehole

The system downsizing also reduced the size of the microbubble generator from 18m to 4.5m. These changes resulted in shallower microbubble generation (Figure 2b), whereas it was at a depth of the formation targeted for injection in 2019 (Figure 2a). Microbubble injection tests were conducted to verify whether the new configurations can still exploit the advantages of microbubble CO_2 by comparing the performance in 2019. The injection rate was set out at 1.5 tonnes per day, the same as last year. The wellhead pressure was 8.4 MPa, whereas the bottom-hole pressure was risen from 8.8 MPa to 14.9 MPa and then was kept at the level. The CO_2 injection index, which is an injection rate per MPa, was 0.25 tonnes/day/MPa. This is comparable with the last year performance of 0.36 tonnes/day/MPa and higher than the performance of conventional injection of 0.09 tonnes/day/MPa. These results proved that microbubble injection with the new configuration is also capable of injecting more CO_2 than the conventional one. The CO_2 storage efficiency was high enough at 82.9%, equivalent to the last year rate.

The field tests demonstrated the validity of the smaller microbubble generator and the improvement of its installing work successfully. This will contribute to cost saving in the production, installation and de-installation of the microbubble injection system.

Our development of the microbubble CO_2 generation technology was initiated by a fundamental study in collaboration with Tokyo Gas. We have acquired a patent of the technology (registered patent No. 5399436), titled "storage device and storage method for stored substances". Through various lab tests and field demonstration, we have completed its development phase. At present, we are attempting to deploy the technology globally, applying it to actual projects, including those in North Dakota in the USA and in Junlun Petroleum Company's field in China.

2.2. Development of Advanced Traffic Light System (ATLS) for the Safety Management of CO_2 Injection

In various underground fluid injection projects, there are concerns that an increase of formation pressure induces earthquakes. Operation in waste water injection and enhanced geothermal systems (EGS), is therefore, managed in a way that prevents induced seismicity around its site with Traffic Light Systems (TLS). According to reports at CO_2 storage sites to date, microseismicity observed there have been limited to a magnitude of 1.1 or less. However, we should deeply consider and implement risk management at a CO_2 storage site, taking the possibility of the seismicity into account.

Our group has been developing a microseismicity management system for CO_2 storage in Japan, called ATLS (Advanced TLS). The requirements for the system suitable for Japan are:

- Capability to extract microseismic events from ground motion data that include data of a number of natural earthquakes and high-level environmental noise caused by human activities,

- Function to determine the hypocenters of micro-seismic events, and
- Capability to process data in real time automatically.

In order to build a management system that meets these requirements, we have been conducting R&D for ATLS using data from the Tomakomai Demonstration Site, where microseismicity has been monitored at its CO_2 storage site. Figure 3 illustrates a schematic view of the workflow of ATLS. After obtaining ground motion data, the extraction of seismic events and the identification of their locations are automatically carried out. In parallel, a latest hypocenter catalog is obtained from the Japan Methodological Agency (JMA), which is used to exclude natural earthquakes from the catalog generated in ATLS.

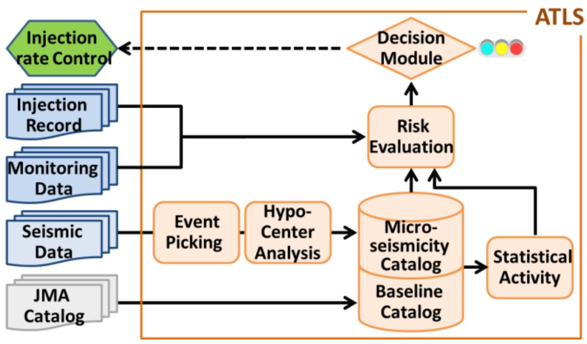

Fig. 3 Flow diagram of ATLS

Using the continuous observation data for 2 years or more in Tomakomai, it was demonstrated that ATLS has the capability to automatically analyze ground motion data and to locate each of the detected microseismic events near at the injection point. Figure 4 shows an image of the output report of ATLS. This presents the frequency and locations of micro- and natural earthquakes in the monitoring area and the colors of traffic light determined by the ATLS.

In addition to the main system, we have developed auxiliary tools to support this system to be more applicable to various sites. An example is to support seismic observation planning which, using a layout of seismometers and an event location as input, calculates an event location to be estimated by ATLS. Comparison the actual event location with the estimated one makes it possible to assess the adequacy of planned seismometer locations and an expected accuracy of event positioning beforehand from the viewpoint of ATLS operation.

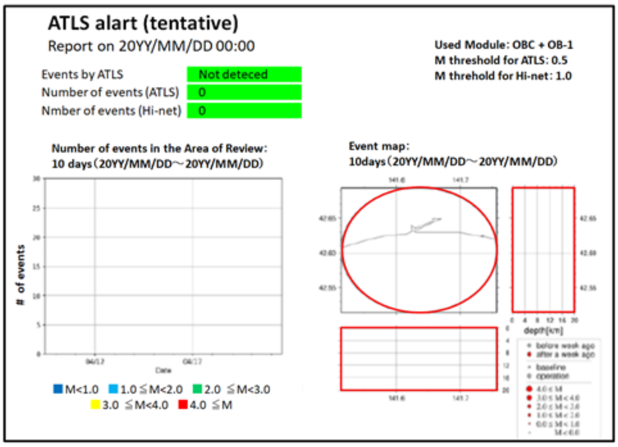

Fig. 4 An example of the output from ATLS

Another example is a tool for the conversion of input data formats. ATLS had initially been designed only for the SEGD format, which is used in the Tomakomai test site. With the developed tool, ATLS is now capable of handling min-SEED and ASCII formats, which are widely used in natural seismic observation.

The validation of ATLS by applying it to the actual CO_2 storage site in Tomakomai and the expansion of applicable sites with additional tools has completed our development of ATLS.

2.3. Integrated system of CO_2 leakage detection and marine environmental impact assessment

Since CO_2 storage sites are deliberately selected to store CO_2 stably and safely, it is considered that CO_2 leakage from the geological reservoirs is remotely possible. Monitoring a CO_2 behavior is, however, still essential as there are public concerns about CO_2 leakage. In addition, when storing CO_2 in the sub-seabed geological formation in Japan, it is mandated to assess marine environmental impacts based on the supposition of CO_2 leakage and to monitor to verify that there are no signs of CO_2 leakage or migration from the reservoir. Hence, our group has studied and developed methods of the marine environmental impact assessment and those of the monitoring for several years. This year, we have combined our developed methods into an integrated system. Here, we outline the methods that we have developed.

For marine environmental impact assessment, we focus on increase of pCO_2 (ΔpCO_2; pCO_2 is an index of CO_2 concentration in seawater). Firstly the distribution of the elevation of pCO_2 is estimated based on supposed CO_2 leakage, and then it is projected how the estimated ΔpCO_2 could impact which organisms. As the leaked CO_2 is dispersed by ocean currents, the distribution of ΔpCO_2 is computed with currents in the sea calculated by an ocean model. The calculation of the distribution of ΔpCO_2 requires a relatively small area, whose sides are smaller than a hundred kilometers. On the other hand, the calculation of the ocean currents needs a much wider area because they are driven under the influence of meteorological conditions and ocean topography over several hundred kilometers. In our method, realistic currents oceanic data are calculated in a larger area model with a lower resolution and then we obtain the calculated current data as the boundary conditions for a simulation of ΔpCO_2 distribution which is simulated in the smaller area with a higher resolution.

The simulated ΔpCO_2 are used to assess what impacts they could make on which organisms. The relation between ΔpCO_2 and its impacts on a marine organism have been reported in many studies, but those data were not compiled into one. We have, hence, constructed a database, with which we can extract correlation between values of ΔpCO_2 and their impacts easily. By given features of organisms (e.g. taxonomic groups, habitats), the database selects organisms that meet the conditions and outputs data on how they could be affected by different levels of ΔpCO_2. Combining the output data from the database and the simulated distribution of ΔpCO_2, we can deduce what kinds of marine organisms could be how affected in which areas.

To identify signs of CO_2 leakage, the scope of monitoring should cover a wide range from deep geological formations, including CO_2 reservoir, to the sea. The reservoir is at a depth of around 1 kilometer or deeper under the seabed. According to a simulation that we conducted previously, the amount of time that CO_2 migrates from a reservoir to the seabed right above would be more than 5 years. Since the pathway of the CO_2 migration would depend on the characteristics of the formations between the reservoir and the seabed, CO_2 would not necessarily leak into the sea in the area right above the reservoir. Taking these into consideration, we propose the following strategy for the monitoring. Initially, we should put the focus on the deep formations including the reservoir to detect signs of CO_2 migration from the reservoir. Then, if detect, we move to in-depth investigation, targeting at overburden, to narrow the potential area for CO_2 to leak out. Lastly, we prove the narrowed area to detect signals of leaked CO_2 in water column.

Regarding the monitoring in the water column, we have explored and developed methods to detect signals of CO_2 leakage. There are 2 kinds of signals of the leakage: one is CO_2 bubbles and the other is elevated CO_2 concentration. Considering that a promising option for detection of CO_2 bubbles is side-scan sonar (SSS, a kind of sonar system), we conducted an in-situ experiment to investigate the capability of SSS to detect CO_2 bubbles in the sea. The experiment was to test whether SSS can detect CO_2 bubbles released on the seabed in various conditions. Our findings include that SSS is capable of detecting bubbles released at a rate of higher than 2-4 tonnes per annum and that the distance between the neighboring observation lines in the monitoring should be shorter than the altitude of SSS (i.e. the distance between SSS and the seabed beneath it). The 4 tonnes of CO_2 are remarkably small quantities; they are comparable to CO_2 that 10 people breathe out in a year.

As to detection of CO_2 concentration elevated by CO_2 leakage, we have studied identification of anomalously high values of pCO_2 caused by CO_2 leakage if any. CO_2 is naturally contained in seawater, and its concentration naturally fluctuates. This makes it challenging to determine whether high pCO_2 values are derived from CO_2 leakage or from natural variability, and to define a threshold for the judgement (Fig. 5). The threshold that we put forward is based on covariance between dissolved oxygen (DO) and pCO_2 (referred to as the pCO_2-DO threshold, hereafter). First, we have examined its validity through an analysis of natural fluctuation in quarterly data of its kind acquired in Osaka Bay, an enclosed bay in Japan, over 9 years. Our conclusions include that, in the identification of anomalous pCO_2 due to CO_2 leakage in summer, when natural variability in pCO_2 is large, or in areas where so is it, the proposed pCO_2-DO threshold is superior to a threshold simply based on pCO_2, and that the threshold should be set out based on data for at least 5 years. As a next step, we have carried out a continuous observation of pCO_2, DO and so on in Osaka Bay more than a year and analyzed their natural fluctuation. This has revealed that pCO_2 in the innermost part of the bay in summer fluctuates largely and that pCO_2 occasionally changes significantly within a few hours. The data over 1 year has revealed that a rate of false-positives to be given by the pCO_2-DO threshold can be varied, depending on seasons. We have also found out that in evaluating the covariance of pCO_2 and DO, it is necessary to take account of a difference in the response times of the sensors. As has been stated, we have proposed the pCO_2-DO threshold to detect signs of CO_2 leakage and clarified its various features, which would be important in actual monitoring operation. It should be, however, highlighted that to detect anomalies in pCO_2 caused by CO_2 leakage at a small leakage rate, it is essential to observe in sea at high resolution both spatially and temporally. This is because dissolved CO_2 is easily dispersed by currents and because even though the leak point is the same, the area where pCO_2 becomes anomalous is varied depending on flow direction and strength and leakage rate. We, therefore, suggest that indexes of CO_2 concentration such as pCO_2 and pH be monitored not for detection of CO_2 leakage but for confirmation that marine environment remains unchanged after commencement of CO_2 storage.

We will incorporate these outcomes into the best practice manual that we have been compiling, hoping that they are used in full-scale offshore CO_2 storage operation.

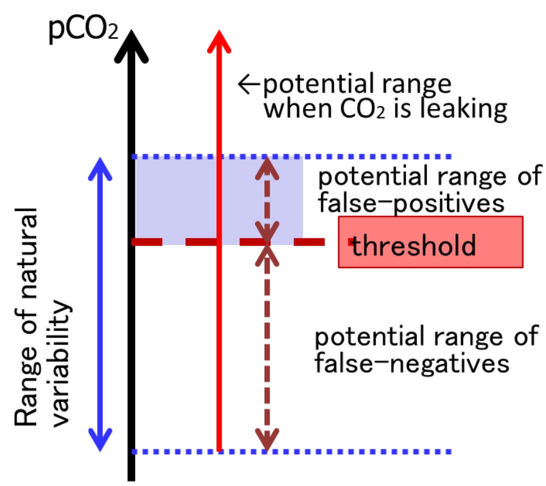

Fig. 5 The relation between the threshold and false-positives and -negatives

2.4. Contribution to the world by cutting-edge technology development

There are a number of large-scale geological CO_2 storage projects in operation worldwide, including Snøhvit in Norway, Quest in Canada, Gorgon in Australia. All these projects have successfully injected and stored CO_2 at about 1Mt/y.

Such large-scale CO_2 storage has unfortunately not yet been implemented in Japan. Nevertheless, our group intends to contribute to global CCS deployment through international cooperation by providing our core competency technologies for large scale geological CO_2 storage.

One of our core technologies is the aforementioned microbubble CO_2 injection technology which improves CO_2 storage efficiency even for low permeability formations. This will enable to use, for example, a CO_2 storage site closer to a CO_2 source, giving more flexibility in site selection. This is a pivotal contributor for CCS promotion in the world. Moreover, we will also strengthen our contribution to CO_2-EOR by demonstrating increased oil production in low-permeability fields in China, which we have been jointly researching with Junlun Petroleum Company since 2018.

Another example is Distributed Fiber Optical Sensing (DFOS). In addition to functions of fiber optical sensing to monitor pressure, temperature and so forth under the ground that have already been used in the oil industry, our group has created our own method to measure strains of geological formations and has integrated and demonstrated them as a multi-sensor system that enables concurrent measurements of temperature, pressure, seismicity and strain of geological formations.

Our DFOS system draws attention not only domestically but also internationally. We have been conducting its demonstration at a commercial CCS site in collaboration with the Energy & Environmental Research Center (EERC), the University of North Dakota, USA. We have built mutually beneficial relationships in this project: the US side is to be able to monitor the stability of the geological CO_2 storage site and CO_2 plume behaviors, and our side has got an opportunity to demonstrate our DFOS system and to improve techniques for its installation at their site.

Our optic-sensing technology will have more and more opportunities to be demonstrated and deployed around the world. It will be, for example, applied to monitor deformation of seabed surface in a European project called SENSE, which is probing the stability of offshore CO_2 storage. There also can be chances for our system to be implemented in CO_2 storage projects being planned in Asian countries.

The promotion of CCS by collaborating internationally is crucial for Japan to achieve our ambitious zero emission goal in 2050. Please keep your eye on the activities of the CO_2 Storage Research Group, RITE. We continue to contribute to CCS deployment by developing innovative technologies and consulting for their applications.