Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

HRE031-01 Room:303 Time:May 24 08:30-08:45

Air-CCS: Climate geoengineering in use of untapped natural energy in remote regions

Hitoshi Koide[1*]

[1]AIST

A new geoengineering scheme ("air-CCS in the remote regions") is proposed to assure the long-term safety of the carbon storage and to overcome the energy penalty for the carbon capture and injection. Because of the concentration of population and economic activities, the energy demands and therefore CO2 emission sources are also concentrated in the restricted industrial and urban regions. The energy demands and CO2 emission sources are rare in the remote regions far from the industrial regions. The wide remote areas in the high-latitude, high altitude and oceanic regions are suitable as CO2 sink areas. The conventional carbon capture and sequestration (CCS) scheme is not viable in the remote areas due to the large infrastructure investment and energy loss for long-distance transportation of huge amount of CO2.

But some new modified versions of carbon capture and technology ("air-CCS") may be viable while CO2 is extracted directly from the atmosphere instead of the flue gas of fossil fuels. The transportation of CO2 is not inevitable for the air-CCS. However, as the atmospheric CO2 concentration is very thin (about 390ppm), the excess energy is required to extract the CO2 from the atmosphere. The unused natural energy (wind, solar, geothermal and natural gas) is used for the recovery of CO2 from the atmosphere and for the underground injection of CO2-rich gas. Energy penalty of air-CCS can be compensated by use of unused natural energy in the remote regions.

The CO2-hydrate-sealed layer is formed at the cool temperature combined with high pressure ("self-sealing") at the aquifers deeper than about 300m in the high-latitude regions such as Canada, Alaska and Siberia, in the high-altitude regions such as the Tibetan plateau and in the sediments under the ocean floor deeper than about 300m. The air-CCS provides vast leakage-free reservoirs beneath the remote regions enough to accommodate all of the excess CO2 in the atmosphere. The air-CCS in the remote areas is the ultimate greenhouse gas mitigation option.

Keywords: geoengineering, CCS, carbon dioxide, greenhouse gas mitigation, natural energy, global warming

Japan Geoscience Union Meeting 2011
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HRE031-02 Room:303 Time:May 24 08:45-09:00

Development of Risk Assessment Tool for CO2 Geological Storage

Atsuko Tanaka[1*], Yasuhide Sakamoto[1], Takeshi Komai[1]

[1]AIST

In this poster presentation,we categorize aspects of risk considerations of CO2 geological storage. Then, we will introduce our risk assessment tool for CO2 geological storage. Our risk assessment tool is consisted from hazard impact estimation part, CO2 migration evaluation part and risk evaluation part. It evaluates CO2 migration in relation with fractures or faults of shallower aquifers and estimates impact of seepage in surface. We are expecting to offer optimum level of quantified value of risk as decision-making basis, and to support safety and risk management of CO2 geological storage legislations.

Keywords: CCS, CO2 geological storage, risk assessment system, impact evaluation

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HRE031-03 Room:303 Time:May 24 09:00-09:15

Simulation of the Effects of Seal Properties on the Long-term Behavior of CO2 Injected Into a Deep Saline Aquifer

Yuki Kano[1*], Tsuneo Ishido[1]

[1]GSJ/AIST

Geological storage of CO2 is one of the methods to mitigate the global warming. Several kinds of reservoir are suggested including depleted oil/gas fields, unminable coal seams, and deep saline aquifers, test and demonstration projects for which are underway. In Japan, saline aquifers without structural trapping are known to keep water soluble methane gas and are considered to be the targets of geological storage of CO2.

If the seal capacity and the continuity of the layer located immediately above the reservoir are sufficient, all injected CO2 is expected to be stored within the reservoir. On the other hand, if they are not sufficient, CO2 gradually migrates upward through the layers during shut-in period. In this case, CO2 will be trapped by multi-layers due to dissolution and residual gas mechanism. We have conducted the sensitivity analysis on the long-term behavior of CO2 injected into a deep saline aquifer, and found that mulit-layers can trap CO2 before reaching the shallow depth even if the seal capacity of single layer is not sufficient.

We treated these seal layers as porous media which have moderate permeabilites in the previous study. However, they are more likely to be composed of mudstone layers with insufficient horizontal continuity. So, to reproduce this situation more appropriately, we adopt the double porosity model to represent the seal layers. If CO2 flows into narrow paths composed of high permeability sandstone (i.e. "fracture region" in the double porosity model), total fluid behavior is thought to be significantly different from that of using the porous medium representation for the entire seal layers. We will present the results of numerical simulations on the long-term behavior of CO2 injected into a deep saline aquifer, using the double porosity model for the moderate permeability seal layers. Numerical simulations are carried out using the "STAR" general-purpose reservoir simulation code with the "SQSCO2" equation of state.

Keywords: Geological storage of CO2, Saline aquifer, alternating layers, double porosity model, numerical simulation

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HRE031-04 Room:303 Time:May 24 09:15-09:30

Semi-permanent continuous monitoring of the CO2 sequestration zone using Seismic ACROSS and multi-geophones Part II

Yoko Hasada[1*], Junzo Kasahara[2], Kayoko Tsuruga[3]

[1]Daiwa Exploration & Consulting Co., Ltd., [2]Shizuoka University, [3]Tokyo Univ. Marine Sci. and Tech.

Carbon dioxide is one of the strong candidates of greenhouse effect which causes the climate change. The geological storage of CO_2 is aimed reduce the emission of CO_2. For secure storage, it is necessary to monitor the physical state of the CO_2-dissolved water stored underground. The monitoring systems using seismic wave are required to be stable for a long term. In seismic reflection processing such as PSDM, 3D effect is extremely important. We propose monitoring the temporal change of reservoirs using the seismic ACROSS, which has high stability to suitable for such monitoring. In this presentation, we report the result of the 3D simulation aiming to examine the effect of source-receiver arrangement and the other measurement setting.

We used the 700m x 700m x 350m geological model and attempted to detect the velocity reduction in 10m cube at 110m depth. A single-force source and ˜40 receivers were placed at the surface. We calculated the wave field for the two cases: with and without the low velocity cube, by means of the finite difference method (Larsen and Schultz, 1995). Then the difference of the waveforms at the receiver points were transformed into the displacements, and back-propagated as the source waveform. The temporal maximums or root mean squares of the amplitude of the wave fields was used to image the place the temporal change occurred.

We used time reversal method (back propagation.) The resultant back-propagation image shows the dependency of the receiver distribution. The presence of a sedimentary layer seems to reduce the resolution, possibly because of the short wavelength in the sedimentary layer. Careful evaluation of the optimal receiver arrangement is required in practice. Another factor affecting the detectability of the objective temporal change is the relation of S/N in the measurement and the magnitude of the temporal change, which concerns the spatial extent and the depth of the target, the change in the physical properties. More detailed investigation for each factor is demanded for the quantitative evaluation of the practical applicability.

Keywords: CCS, CO2 sequestration, time lapse, ACROSS, back propagation, time reversal

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HRE031-05 Room:303 Time:May 24 09:30-09:45

application and analysis of water-rock-carbon dioxide reaction using basalt

Tomohiro Katayama[1*], Naotatsu Shikazono[1], Yutaro Takaya[2], Yasuhiro Kato[2]

[1]Graduate School, Keio University, [2]Graduate School, University of Tokyo

Water-rock-CO_2 reaction is important in many parts of science. Main reactions are as follows.
$CO_2 + H_2O = H_2CO_3 = H^+ + HCO_3^-$ (1)
$MSiO_3 + 2CO_2 + H_2O = M^{2+} + H_4SiO_4 + 2HCO_3^-$ (2)
$M^{2+} + 2HCO_3^- = MCO_3 + CO_2 + H_2O$ (3)
M is divalent metal ion.

There are two steps. First, CO_2 dissolves into water at (1) and mineral($MSiO_3$) and water react with CO_2 at (2). Next, divalent metal ion and HCO_3^- react and precipitation occurs at (3).

We will apply it to the CO_2 underground sequestration and the estimate of Archean atmospheric CO_2 concentration and global carbon cycle and materials of subsystem.

Keywords: basalt, water-rock reaction, CCS, the dissolution rate constant, simulation

Japan Geoscience Union Meeting 2011
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HRE031-06 Room:303 Time:May 24 09:45-10:00

Experimental study for the CO_2 geological storage in Green-Tuff Region in Japan

Yutaro Takaya[1*], Kentaro Nakamura[2], Yasuhiro Kato[1]

[1]Sys. Innovation, Univ. of Tokyo, [2]PEL, JAMSTEC

The Green-Tuff region in Japan is regarded as a suitable candidate of CO_2 geological storage. In Japan, the Green-Tuff rock is widely distributed in the region from the Sea of Japan side to the western Hokkaido. The Green-Tuff rocks have high permeability and porosity and contain relatively high cation abundances of K, Mg and Fe that govern acid neutralization potential of rock and formation of stable carbonate minerals (geochemical trapping of CO_2). In addition, it is very unlikely that the large scale implementation of CO_2 geological storage causes social problems such as water resource pollution because almost all the aquifers in the Green-Tuff region are saline aquifers and are of no economical value.

We selected the Tugawa formation as a potential site of CO_2 geological storage in the Green-Tuff region and collected the Green-Tuff rock samples from the Hukutori Green-Tuff sub-formation corresponding to the upper part of the Tugawa formation. We examined physical and chemical properties of the rocks and conducted CO_2-water-rock (Green-Tuff rock) interaction experiments to predict the long-term behavior of injected CO_2. In our presentation, we evaluate the long-term CO_2 fixation by the dissolution rate of the Green-Tuff rock and discuss a CO_2 storage capacity in the Green-Tuff region.

Keywords: CCS, CO_2 geological storage, water-rock interaction, Green-Tuff

Japan Geoscience Union Meeting 2011
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HRE031-07 Room:303 Time:May 24 10:00-10:15

Inorganic precipitations of marine carbonate in sandstone do not release CO2 outside: Evidence from Sr, O and C isotopes

Minami Masayo[1], Tsuyoshi Tanaka[4*], Takeuchi Makoto[2], Mito Saeko[3]

[1]Center for Chronological Res. Nagoya Uni, [2]Earth and Environmental Sci. Nagoya Univ, [3]RITE, [4]CCR Nagoya Univ. and RITE

87Sr/86Sr,delta 18O and delta 13C isotopes of carbonate in calcareous sandstone indicate simultaneous formations of the 1st-carbonate precipitation from seawater with 2nd-precipitation of carbonate by the reaction silicate and released bicarbonate ion. Triassic Hiraiso Formation of the South Kitakami Terrane contains calcareous sandstone. It is considered that the early Triassic period was a dried climate and the Hiraiso Formation was deposited at near shore marine. Carbonate phase and silicate phase are separately examined. 87Sr/86Sr and delta 18O isotopes of the carbonate phase were lower than the values of limestone at that time. The values show the intermediate between silicate minerals and marine carbonate, while delta 13C shows the value of marine carbonate. The carbonate distributed homogeneously in lithic fragments and partly replaced plagioclase. The 87Sr/86Sr and delta 18O isotopes are the mixed values of marine strontium and oxygen with silicate strontium and oxygen. Very small carbon is contained in the silicate phase and the value shows always that of marine.

Keywords: carbon dioxide, geological storage, Sr isotope, O isotope, C isotope, calcaleous sandstone

Japan Geoscience Union Meeting 2011
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HRE031-08 Room:303 Time:May 24 10:15-10:30

A solution to CO_2 geologocal storage ploblems in Japan

Shinichi Hiramatsu[1*], masao Ohoka[1], Hiroshi Kameya[1], Junya Takeshima[1], Hiroyuki Azuma[1]

[1]Oyo coporation , Energy bisiness divisio

Geological structure of the Japanese Islands is very complex because that is located in front of the subduction zone of the Pacific Plate and Philippine Sea Plate. The geological storage project near the emission source in Japan must target relatively younger formations. In this circumstance, there are the specific geological problems of Japan that must be solved.

1) Sealing efficiency of the seal formation (mechanical stability and large porosities).
2) Uncertainty of CO_2 movement in the inhomogeneous reservoir.
3) Treatment of the active faults and folds that form the basins (i.e. reservoirs).
4) Small capacities of one reservoir (basins).

We have conducted several study to solve its geological problems and to build Japan-type CCS.

a) Mechanical stability of soft seal formations.
b) Capillary sealing efficiency of soft seal formations.
c) Accurate reservoir models using seismic inversion and rock physics.

Keywords: CO_2 aquifer storage, Japan-type CCS, Soft seal formation, Mechanical stability, Capillary sealing efficiency, Seismic inversion

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HRE031-09 Room:303 Time:May 24 10:45-11:00

On the Geological Storage Research at AIST

Shinsuke Nakao[1*], Toshiyuki Tosha[1]

[1]AIST

A large-scale demonstration project has been conducted by METI for CO2 geological storage. To provide technical support, we have embarked on the 2nd phase of CO2 geological storage research aimed at creating a versatile, general-purpose technical foundation.

We have launched research in the following areas commissioned by the Research Institute of Innovative Technology for the Earth (RITE) under a Ministry of Economy, Trade and Industry grant: Enhancement of the precision of simulation models for predicting long-term behavior, Development of combined monitoring methods and Development of methods of assessing CO2 movement in interbedded sandstone and mudstone formations. We will also apply a geophysical postprocessor for the STAR general-purpose reservoir simulator, which was originally developed for geothermal research, to predict CO2 behavior.

Moreover, the joint research works with US research institutes were started. For development of cost-effective monitoring technology, we will collaborate with the Los Alamos National Lab. For development of modeling technologies including geomechanical processes, we collaborate with the Lawrence Berkeley National Lab.

Some of these works were performed under the management of the Ministry of Economy, Trade and Industry (METI) as a part of the research and development on CO2 geological sequestration project conducted by RITE.

Keywords: CCS, CO2, Geological Storage, Modeling, Monitoring

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HRE031-10 Room:303 Time:May 24 11:00-11:15

An injection experiment with small amount of Carbon Dioxide(2)

Toshiyuki Tosha[1*], Akinobu Miyakoshi[1], Shinichi Takakura[1], Tomio INAZAKI[1]

[1]AIST

As energy production with the fossil fuel is inevitable for continued economic development, a practical application of the CCS technology is requested that extracts CO_2 from the exhaustion gas of the fossil fuel and store it into the geological formation in order to reduce the discharge of CO_2 into the atmosphere. The development of the CO_2 geological storage technology in CCS is advanced at the geological units in AIST. The behaviour of the injected CO_2 in the saline aquifer has been clarified in the AIST research works as well as the development of the monitoring technology in the CO_2 geological storage.

At the CO_2 monitoring, seismic monitoring is most often used. High resolution of the result is obtain and the strong seismic refraction and the low velocity change are expected at the boundary between the brine and the super-critical or gaseous CO_2 when CO_2 is stored widely with certain measure of thickness. CO_2 is, however, expanded widely and the width of the stored CO_2 is small at the end of the storage layer. Moreover CO_2 is expected to be dissolved. The dissolved and thin CO_2 is hard to detect by the seismic refraction method. On the other hand the resistivity is very sensitive for the dissolving CO_2. Core sample experiments suggested that the seismic velocity reduces during the injection of CO_2 with the lower relative permeability but there is a small change at the relative permeability more than 20% (Lei and Xue, 2009).

The advantage of the seismic exploration and the domination of the resistivity survey are confirmed by the field experiment. To examine the analysis taking the advantages of the both exploration methods into account, a field experiment was carried out where gaseous CO_2 was injected into a shallow aquifer using a shallow well in AIST (Tosha et al., 2010). The saline aquifer is located at the depth of 47.5m below the ground level. The resistivity was hard to measure due to various types of artificial deposits and the iron casing pipe set till the depth of 45m. A test well with a depth of 150m was drilled at the test field in Hokkaido. The polyvinyl chloride casing pipe was selected to make less influence to the resistivity measurements. The continuous temperature monitoring was carried out at the bottom of the injection well in AIST (Miyakoshi et al., 2010). The same monitoring tool was used. The temperature logging was also conducted before and after the CO_2 injection. This work was performed under the management of the Ministry of Economy, Trade and Industry (METI) as a part of the research and development on CO_2 geological sequestration project conducted by RITE.

Keywords: CO2, geological storage, grobal warming, monitoring, temperature logging

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HRE031-11 Room:303 Time:May 24 11:15-11:30

Gas adsorption capacity of shales -Study on geological CO_2 storage in coal-bearing formation-

SOHEI SHIMADA[1*], Yuki NISHIIRI[1], Naoto SAKIMOTO[1], Kotaro OHGA[2]

[1]The University of Tokyo, [2]Hokkaido University

CO_2 and CH_4 adsorption capacity of five shales (Bibai(Japan), Kusiro(Japan), Yubari(Japan), Illinois(USA) and gas shale (PA, USA)) are measured by volumetric method at the temperature of 35C and 50C in a pressure range from 0 - 9 MPa. Every shales have a certain amount of adsorption capacity.

The Yubari shale exhibited the largest CO_2 adsorption capacity of 14cc/g, which is equivalent to the middle CO_2 adsorption capacity. The adsorption of shales is not negligible in CO_2 storage in coal-bearing formation.

Keywords: Shale, Coal-bearing formation, CO2, Geological storage, Adsorption, Coalbed methane

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HRE031-12 Room:303 Time:May 24 11:30-11:45

Gas flow in ECBMR in coal-bearing formation -Study on CO2 storage in coal-bearing formation-

SOHEI SHIMADA[1*], Kei TANAKA[1], Ryota NISHIZAWA[1]

[1]The University of Tokyo

The authors are engaging in the development of geological CO2 storage simulator ECOMERS(CBF)-UT, enabling the simulation for both coal seam and aquifer. Gas flow analysis for model coal-bearing formation composed of two coal seams and one aquifer showed a interesting feature. CBM production history from upper coal seam has complex production rate due to the mixture of CBM from lower coal seam. CH4 and CO2 flow analysis, which affects the CBM production rate and CO2 storage amount are presented.

Keywords: Coal-bearing formation, CO2, Geological storage, Enhanced coalbed methane recovery, Gas flow, Simulation

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HRE031-13 Room:303 Time:May 24 11:45-12:00

Affairs of solidified carbon dioxides at high temperature on Earth planet and artificial industry

Yasunori Miura[1]*

[1]Yamaguchi University

The present results are summarized as follows.

1. The global warming is a global phenomenon of the Earth planet. The artificial issue of carbon dioxide increase requires global idea of Earth planetary correspondence effectively, not for local correspondence.

2. Circulation reactions of living entity with breathing process at low temperature and carbonate mineral formation in ocean water from carbon dioxides, are state-changes with solidified reaction of relatively lower temperature. Oxygen generation and carbon dioxide decrease from the living entity (a plant etc.) of the Earth history are mainly based on this type of effective reaction at low temperature.

3. Artificial outbreak of carbon dioxide after the social Industrial Revolution, are discharged it at high temperature from a chimney and a combustion exhaust pipe (by oil and coal combustions) to the sky without any state changes directly.

4. Compared with terrestrial atmosphere at lower temperature (i.e. in active planet at lower and higher temperatures), the Venus with air of carbon dioxides at higher temperature is the planet with remaining intact without a state changing after the volcanism and meteoritic collision at higher temperature (i.e. planet with interrupted activity during higher temperature). Mars is planet with air of carbon dioxides at lower temperature to stop Martian volcano and carbonate solidified formation via the seawater now, and present active state-changes of between air and the polar capes of dry ice solids(i.e. in active planet with lower temperature). The small bodies of airless Moon and Asteroids are mainly stopped bodies with solidified rocks and without global state-changes (i.e. globally stopped bodies without main state-changes).

5. The increase of artificial (industry) production in carbon dioxides with high temperature change on the present Earth is similar with the Venus activity. However, we can expect global activity development of carbon dioxides controlled by decreases of a temperature of the Venus in future, as well as stop of global warming on the Earth, which are applied by direct produced state-change of carbon-bearing materials at higher temperature to prompt decrease of the hot gas.

6. Decrease method of industrial carbon dioxides should be used properly for our global idea and method of direct fixing at higher temperature (Miura, 2007). In this sense, other reported methods are considered to be local and bubble (science)-like methods with an energy waste to apply complex process (without global idea).

Keywords: carbon dioxides at high temperature, carbon dioxides at low temperature, Earth planet, industrial gas, state change, global idea

Japan Geoscience Union Meeting 2011
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HRE031-14 Room:303 Time:May 24 12:00-12:15

Seismic anisotropy due to CO2 replacing water

Xinglin Lei[1*], Ziqiu Xue[2]

[1]AIST, [2]RITE

Geological sequestration of Carbon dioxide (CO2) into saline aquifers or other geological structures has been proposed to reduce the volume of CO2 emission to the atmosphere for the purpose of stabilizing the global warming. Monitoring, verification and environmental safety of CO2 storages are important issues must be addressed before the technology can be accepted by the public for wide scale implementation. If mitigation is required at any point, an accurate estimation of CO2 distribution would be necessary. By now, seismic surveys provide the most attractive approach for obtaining the spatial coverage required for mapping the location and movement of CO2 in the subsurface. Sedimentary aquifers are normally characterized as to be seismically anisotropic medium. On one hand, such anisotropy should be considered in the interpretation of seismic method such as velocity tomography (Lei & Xue, 2009). On the other hand, seismic anisotropy is also meaningful for monitoring CO2 distribution because it is sensitive to CO2-saturation in the pore volume of sedimentary aquifers.

This study aims to make clear the elastic response of typical porosity rocks due to CO2 replacing water as well diffusion of pore-pressure. Gaseous, liquid and super critical CO2 were injected into well-prepared porous rock sample under well-controlled conditions in laboratory. During the injection seismic measurements are performed frequently along many paths, from 8 x 8 to 16 x 16. Then both P-wave velocity and attenuation are imaged using difference tomography techniques. The ongoing study has two main issues. Firstly, we focus on modeling the change of the petrologic properties of typical porosity rocks due to displacement between water and CO2 gas. Secondly, we aim to improve the monitoring techniques applicable in fields, particularly the seismic tomography method, for making precise estimation of the CO2-saturation fraction in an aquifer.

Experimental results indicate that the velocity anisotropy shows strong dependence on contains in the pore volume. For example, in a test sample of Tako sandstone (24% porosity), the estimated ? values, a measure of velocity anisotropy, are 0.15 and 0.075 for dry and water saturated conditions, respectively. After the injection of gaseous CO2 in to the water saturated sample, the optimum value of ? is estimated as 0.1. It is verified that taking the seismic anisotropy into consideration is unavoidable for precise monitoring.

[Acknowledgement] This work was performed under the management of the Ministry of Economy, Trade and Industry (METI) as a part of the research and development on CO2 geological sequestration project conducted by RITE.

Reference:

Lei X.-L., Z. Xue, 2009. Ultrasonic velocity and attenuation during CO2 injection into water-saturated porous sandstone: Measurements using difference seismic tomography. Phys. Earth Planet. Inter. 176, 224-234.

Keywords: CCS, Elastic wave, Anisotropy, Laboratory

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HRE031-15 Room:303 Time:May 24 12:15-12:30

Monitaring subsurface CO2 condition by applying rock physics

Osamu Nishizawa[1*], Tatsuya Yamada[2], Ziqiu Xue[1]

[1]Res. Inst. Innovative Tech. Earth (RITE), [2]Graduate School Engineering, Kyoto Univ.

Geophysical monitoring is important for evaluating stability of CO2 at CO2 sequestration sites. Since physical properties of rocks are controlled by fluid states in pores or cracks, changes of physical properties of rocks will help us to understand CO2 behavior at CO2 reservoir or cap rocks which seal the isolated CO2.

The most notable change will appear when gaseous CO2 appear in pores or cracks. The seismic anisotropy and the complex resistivity will be very much affected by gaseous CO2 in rocks. Considerable changes of seismic anisotropy in mudstone will be expected when gaseous CO2 appears in pores. Gaseous CO2 also affects complex resistivity in sandstone, where phase delay between current and voltage appear in the low frequency range between 100 Hz and 0.01 Hz. Those characteristics will be applicable to understand well log data at CCS sites in connection with CO2 behavior.

Mudstones often show anisotropy in which seismic velocity distribution is characterized by an angle from the unique axis. This is called transverse isotropy (TI). In anisotropic media, wave vibrations are generally not parallel (P wave) or orthogonal (S wave) to the propagation directions. Those are called quasi-P (qP) wave and quasi-S (qS) wave. In TI, qS wave is often referred to as qSv wave because vibration direction is perpendicular to Sh wave which vibrates parallel to the isotropic plane. The velocity difference between Sh wave and qSv wave indicates shear wave splitting. When fluids in pores and cracks change from liquid to gas, anisotropy will change. The change of anisotropy is characterized by using shear-wave splitting. The change in shear-wave splitting can be studied by a model which contains oriented cracks within a TI medium. By using the model, we can estimate the change of shear-wave splitting when fluid in cracks changes from liquid to gas. The estimated change in shear-wave splitting for one of natural mudstones is more than 4 %. This amount of change in shear-wave splitting can be measurable in field observations.

Another important change in the reservoir rock is the electrical impedance of rock. Rock electrical impedance is characterized by frequency response of real and imaginary parts of the impedance, associated with the phase difference between current and voltage in the frequency range between 100 Hz and 0.01 Hz. This is explained as a relaxation process of ion movement near the electric double layer. Since gaseous CO2 in pores controls the distribution of the electric double layer in rock, the change of complex resistivity is associated with the states of CO2 in the reservoir of CCS site.

Keywords: CCS, rock physics, seismic velocity, anisotropy, rock resistivity

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Experimental study for CO2 migration monitoring to estimate P-wave traveltimes and amplitudes by drainage and imbibition

Susumu Sakashita[1*], Keigo Kitamura[1], Dai Nobuoka[2], Hiroyuki Azuma[2], Junya Takeshima[2], Hideki Saito[2], Ziqiu Xue[1]

[1]RITE, [2]OYO corporation

We conducted laboratory experiments to examine the change of P-wave travel times and amplitudes, which correspond to decreasing water saturation during drainage and increasing saturation during imbibition, using Tako sandstone. Travel times increased and amplitudes decreased abruptly during drainage and the change of travel times appeared a little faster than amplitudes. During imbibition, travel times and amplitudes changed gradually. Travel times reached to constant values a little faster than amplitudes.

We reviewed time-lapse seismic tomography datasets before and after CO2 injection same as drainage, and 5 years post injection in progress like imbibition at Nagaoka pilot site. These results indicate that the change of parameters were consistent with the laboratory experiments in drainage, although the imbibition was not recognized. It is useful to examine both travel times and amplitudes in the next measurement because of prediction for slight and gradual change parameters during imbibition.

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Data analysis of time-lapse well logging results for the monitoring of stored CO2 at the Nagaoka pilot site

Takahiro Nakajima[1*], Ziqiu Xue[1], Saeko Mito[1]

[1]RITE

Monitoring of the CO2 in the underground is one of the essential technologies to carry out CO2 geological sequestration safely. At the first Japanese pilot CO2 injection site (Nagaoka), well loggings which are consist of sonic, neutron, and induction loggings have been continued for more than 6 years. The time-laps well logging at Nagaoka provide the CO2 behavior around the observation log. To improve understanding of the trap mechanism of CO2, rock physics model which relates the physical parameters (modulus etc.) and reservoir parameters (permeability, saturation etc.) would be important. We study the rock physics model at Nagaoka using the well logging data with an estimation of measurement errors.

Keywords: CO2 geological storage, Well logging, monitoring, Nagaoka

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HRE031-18 Room:303 Time:May 24 14:30-14:45

Design of experimental facility for steady state relative permeability measurements in water-supercritical CO2 systems

Tetsuya Kogure[1*], Ziqiu Xue[1]

[1]RITE

Relative permeability curves are important to simulate the movement of multiphase flow in porous media. Carbon dioxide capture and storage technologies (CCS) require the information about relative permeability curves to predict the behavior of CO2 injected into reservoirs which are usually located at about 1000 m under ground. The CO2 in the reservoirs are in supercritical phase due to the reservoir conditions (40oC, 100 atm). Therefore, laboratory experiments were conducted to measure the relative permeability in water-supercritical CO2 systems.

Laboratory measurement techniques for relative permeability determination are of two sorts. The most reliable relative permeability data are obtained by steady state methods in which two or three fluids are injected simultaneously at constant rates or pressure for extended durations to reach equilibrium. The saturations, flow rates, and pressure gradients are measured and used in Darcy's law to obtain the effective permeability for each phase. Conventionally, relative permeability curves vs. saturation are obtained, in a stepwise fashion, by changing the ratio of injection rates and repeating the measurements as equilibrium is attained.

Relative permeability measurement systems usually consist of a core holder, pumps controlling the pressure and the flow rates of flows in the core, and separator. Relative permeability can be calculated from the measurement of the changes of liquid level through the separator. However, the pressure resistance of almost all separators in many researches is too low to be used for the experiments mimicking reservoir conditions. This fails to measure the volume of CO2 precisely because of the change of the CO2 phase. Therefore, a new separator with high pressure resistance was made and used for this measurement.

The rock samples, Berea and Tako sandstone, are 5 cm diameter cylinders with a length of 10 cm and absolute permeability of 10 mD. The samples are saturated with water in which CO2 is dissolved just before the measurements. Then water and supercritical CO2 are co-injected in different proportions (fractional flows) to measure a relative permeability curve: the conditions are 40oC and 100 atm, and the injection flow rate is 0.5 ml/min in total. Steady state flow is achieved by continuous experiments over 3 days for Berea sandstone and a week for Tako sandstone. Although the measurements take a long time, steady state relative permeability in water-supercritical CO2 systems can be measured through our experimental facility.

Keywords: relative permeability measurements, steady state, water-supercritical CO2 systems

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HRE031-19 Room:303 Time:May 24 14:45-15:00

Relative Permeability Experiments for Estimating CO2 Movement

Hiroshi Kameya[1*], Kohichi Hosoda[2], Masaki Ono[2], Yotsuo Kamidozono[2], Junya Takeshima[1], Hiroyuki Azuma[1], Shinichi Hiramatsu[1]

[1]OYO Corporation, Energy Division, [2]OYO Corporation, OYO Core Lab

Carbon dioxide Capture and Storage is thought now as an option of green house gas reduction. Saline aquifers are most possible target for the geological sequestration in Japan. There are still many unknown factors for geological sequestration into saline aquifers such as how CO2 will spread and move in saline aquifer or how is the possibility that CO2 will penetrate through low permeable formations and reach to surface. Many numerical simulations have been done for geological sequestration into saline aquifers, but there are still few data about two phase flow properties such like relative permeability using CO2 in super-critical condition.

Many relative permeability measurements have been done in petroleum reservoir engineering for a long time and two laboratory experiment methods, steady state method and unsteady state (displacement) method, represent them. In the steady state method two fluids are injected into the specimen at pre-determined rate, and the permeability can be calculated from flow rate of either fluid and pressure difference between both ends of specimen. But the steady state method doesn't meet the general process in fluid storage or production, where one fluid is displacing the other. In the unsteady state (displacement) method, one fluid of wetting phase which saturates a specimen is displaced by other fluid of none-wetting phase.

To evaluate the relative permeability from the unsteady state experiments, however, analytical or numerical method is needed because the saturation in the specimen is not homogeneous during displacing process. The JBN method is generally used in petroleum reservoir engineering, which is one of the analytical methods for one dimensional displacement (or oil-recovery) problem. Because this method needs the derivation of the measurements such like flow rates and pressure difference, the results using the measurements directly might be erroneous, so some adequate approximations of the measurements or other manipulations should be done. In addition, the flow condition that is assumed in the JBN method, neglect the effects of capillary pressure, compressibility of fluids and gravitational force, so the JBN method is inadequate if these effects are serious. In many researches the history matching techniques are adopted to derive the optimal relative permeabilities by using two phase flow numerical simulations and minimal residual routines.

On these backgrounds, we have made new experimental equipment on permeability test for rocks using super-critical CO2. Our experiment is based by the displacement method and the saturation of the specimen is calculated by fluid volume balance. For the volume measurements, a separator corresponding to high pressure was set through the outlet line so that the flow-out fluids from the specimen separate here. To evaluate saturation of specimen, we must consider the storage volume (or dead volume) in the line that affects total fluid volume which flows into and flows out from the specimen. There are two portions of line that constitute the dead volume, one is the in-flow part from the injection syringe pump to the specimen and the other is out-flow part from the specimen to the separator. The former has been detected by the flow rate and pressure change when displacing fluid reaches to the top of specimen. The latter was measured initially and reduced from the total outflow volume.

Some sandstones and mudstones were tested to evaluate relative permeabilities. The test results has revealed following facts.

1)Relative permeabilities of displacing CO2 calculated by average flow rate are almost equal to those by JBN method, but those of the displaced water are somewhat different.

2)The simulations using Tough2 with the relative permeability by JBN method, can reproduce the test behaviors.

3)Theoretical models such as Corey(1954) doesn't match with our test results, so more flexibility is needed to model the test results.

Keywords: CCS(Carbon dioxide Capture and Storage), Two Phase Flow, Relative Permeability, Laboratory Experiment

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HRE031-20 Room:303 Time:May 24 15:00-15:15

The rock physical approach to the complex CO_2 flow in the beded Tako sandstone

Keigo Kitamura[1*], Ziqiu Xue[1], Tatsuya Yamada[2], Osamu Nishizawa[1]

[1]RITE, [2]Kyoto University

In this study, we try to elucidate the effect of thin low-porosity layer in porous Tako sandstone on CO_2 flow by experimental and theoretical studies. Tako sandstone is early Miocene marine sandstone, mainly composed of quartz and plagioclase. This rock is characterized by the well-developed and low porosity foliations are mainly composed hematite. We have measured two channels of P-wave velocities (Vp) on the foliation channel (LPZ) and high porosity zone (HPZ) by using 1MHz P-wave transducers during CO_2 injection stage (drainage) and water re-injection stage (imbibition). In drainage, both of channels show large velocity reduction over 0.2 km/s (>10 %). In imbibition, they indicate different Vp-change with injecting water. The Vp of HPZ starts the Vp-recovery from 50ml injection and almost recovers at 120ml.On the other hands, LPZ starts Vp recovery from 100ml water injection and do not finish at 250ml. These results suggest that the HPZ has large CO_2 mobility and the LPZ has different CO_2 flow pattern between drainage and imbibition. Next, we try to 2D core-scale flow simulation by TOUGH-2 to check and discuss about CO_2 behavior in Tako sandstone. This simulation is based on 2-D porosity distribution map of core and uses relative permeability for parameters. The result of our simulation indicates that the foliation (LPZ) has large trapping potential of CO_2. The HPZ, which is directly beneath of foliation zone (DBFZ), has large CO_2 saturation in early stage of drainage. We confirm that CO_2 have large mobility and vigorous vertical flow in HPZ. After reaching upper foliation, CO_2 flows laterally along foliation and raise saturation of whole HPZ. In imbibition, CO_2 saturation of HPZ decreases rapidly to assign residual CO_2 saturation over 40ml water injection. However, DBFZ keep high CO_2 saturation after 100ml water injection. On the other hands, CO_2 saturation of LPZ is smaller than HPZ in drainage stage, but they show large saturation value over 20ml water injection. These results suggest that the foliation of Tako sandstone behaves as a barrier of CO_2 flow. It is implied that the thin low-porosity layer may be a barrier of CO_2 flow in porous saline aquifer.

Keywords: P wave velocity, foliation, CO_2 flow pattern, porosity distribution, CO_2saturation, TOUGH-2

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Visualization technique of CO2 storage mechanisms using X-ray computed tomography

Yukihiro Yazaki[1*], Shun Chiyonobu[1], Ziqiu Xue[1]

[1]RITE

Carbon Capture and Storage (CCS) is one of the useful means to reduce CO2 to the atmosphere. The captured CO2 gas in industrial and energy-related sources is injected into deep geological formations. In order to assess the long-term risk of injected CO2, it is necessary to elucidate the storage mechanisms, such as geological characteristics and movement of CO2.

We show the visualization technique of CO2 storage mechanisms using a medical X-ray computed tomography (CT). X-ray CT is a medical imaging method employing tomography created by computer processing and can produce a three-dimensional image of components both externally and internally.

1) Characterization of geological formations

Basic properties, such as pore shape, pore size distribution and porosity, are usually determined by cutting samples from the whole core. These analyses are suitable for complex reservoir characterization. On the other hand, the X-ray CT scanner is a powerful tool for nondestructive analysis of geological materials. Utilization of conventional core analysis and CT scanning will make possible accurate evaluation of rock properties and geological formations.

2) Elucidation of CO2 flow and transport processes

The effectiveness of geological storage depends on a combination of physical process (e.g. residual CO2 gas trapping) and geochemical processes of solubility trapping and mineral trapping. Therefore, we have to develop a greater understanding of these trapping mechanisms. Experiments of residual gas trapping are conducted with X-ray CT scanning. These experiments are designed to allow monitoring the evolution of trapped gas over time (4-D). Measurements of gas-water saturation with geophysical properties will be undertaken in this study.

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Geological features of reservoir formation of Nagaoka CO2 injection Site, based on the sedimentary facies analysis

Shun Chiyonobu[1*], Yukihiro Yazaki[1], Ziqiu Xue[1]

[1]RITE

Nagaoka CO2 ingection Site in the Niigata plain is the largest oil field in Japan. At present, the aquifer of this oil field in Miocene to Pliocene have been proven since the beginning of systematic evaluation and exploration for the carbon dioxide capture and storage (CCS). Nagaoka injection Site is located in the central part of the Niigata basin, where there is the favorable geological conditions for forming aquifers. The aquifers widely distributed in the Niigata basin was deposited widely the paralic to hemipelagic environment during the Neogene. The superimposed fluvial_delta to marine deposits distributed approximately from north to south have constituted the complex sandstone aquifer in Nagaoka area. Under the background on the end shape of anticline, the aquifer is lay lenticular formation. As a result, a large area lithologic trap for the CCS was formed in Nagaoka area. The core sample included high contents of medium to coarse sandstone and tuff as well as the dissolution and erosion of volcanic matters were useful for understanding the forming the high porosity and permeability reservoirs.

Keywords: aquifer, porosity, particle size analysis, sedimentary facies