Trapping mechanisms in field scale observed by time-lapse well logging at the Nagaoka site

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This paper discusses CO_2 trapping in field scale observed at the Nagaoka pilot-scale injection site. IPCC (2005) illustrated the contributions of various trapping mechanisms over time, and pointed out the importance of capillary and solubility trapping at the early stage of geological CO_2 storage. Capillary trapping is caused by interfacial forces at the pore of rock and prevents migration of CO_2 bubble. Solubility trapping means that gaseous CO_2 dissolves into formation water. After the report of IPCC, many laboratory experiments related to these trapping mechanisms have been conducted. Meanwhile, field observations were limited. In this paper, we study trapping mechanisms observed at the Nagaoka site.

Nagaoka project was undertaken in order to verify an ability of CO_2 injection into Japanese formation. The target reservoir is consists of a limb of anticline structure and have 15 degree dipping. About 10 k-tones of CO_2 were injected into a thin permeable zone from July 2003 to January 2005. Time-lapse well loggings have been carried out for more than 12 years, and the number of monitoring logging is 44 times so far. CO_2 breakthrough was detected at a down-dip well (OB-2) located 40m away from the injection well, and at a up-dip well (OB-4) located 60m from the injection point. From the neutron logging data, CO_2 saturation in super-critical phase was evaluated, and from the induction logging the existence of super-critical and dissolved CO_2 is deduced. At OB-2, CO_2 saturation peaked at 63% around 22 months after the start of injection, decreased gradually, and stabilized at around 20%. At OB-4, CO_2 saturation peaked at 69% around 15 months and remained relatively high value (40%).

We considered that the maximum saturation at each depth was corresponding to the initial saturation of drainage process and the latest observation could be assumed as the residual state. The relationship between the initial and residual saturation is called IR curve and represents the fundamental flow properties in drainage process. The results at OB-2 showed that most of the data can be explained by single Land’s model. Exception came from relatively silty layer, which means pore distribution is different from other layers. At OB-4, IR relationship was scattered and indicated that the latest state is far from the residual condition. The difference between down- and up-dip direction is thought to exhibit migration effects in the reservoir.

Concerning the dissolved CO_2, the thickness of the low resistivity anomaly became larger. This showed that the solubility trapping was progressing. The rate of thickening was the same order as the dissipation of bicarbonate ion. This was consistent with the expectation from the linear instability theory for density convection of CO_2 dissolved water.

These results showed capillary and solubility trapping mechanisms in the field scale observation. The drainage process in field scale could be explained by Land’s model as laboratory experiments, and the fitted model was depend on rock type. Solubility trapping in several mD formations was confirmed that dissipation process was dominant during the first decade of CO_2 storage. These results could be used for simulation tasks to build a better flow model.

Keywords: CO2 geological storage, multiphase flow, residual trapping, solubility trapping, Land model, Nagaoka site

Visualization and measurement of CO_2 microbubble flooding in heterogeneous sedimentary rock

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We carried out laboratory experiments of CO_2 microbubble and normal bubble flooding in porous sandstone to confirm the difference in dissolution and sweeping effect. During the experiments, we obtained the specimen porosity and monitored fluid saturation process by using CT image analysis. Sarukawa sandstone (diameter: 34.80mm, length: 79.85mm, north central Japan) was used in this study. Porosity of specimen determined by X-ray CT imaging is 30.94%. The specimen has heterogeneous structure. The experiments were conducted under the pressure and temperature conditions that simulate underground environments; pore pressure: 10MPa, temperature: 40 degrees Celsius. The confining pressure selected in this study is 12MPa. The specimen was first saturated with KI aqueous solution (12.5%), and then oil was injected to make oil-water mixed state. Totally, ten steps of flooding were performed for each experiment. For each step, KI aqueous solution and oil were carefully recovered from the syringe pump (back pressure pump). We increased the differential pressure to examine the influence of differential pressure on oil recovery in heterogeneous media. The microbubble and normal bubble flooding tests were carried out until the total fluid injections reach about 3PV (pore volume). Figures a) and b) show the differential CT images when the CO_2 microbubble and normal bubble injections reach 2.95PV and 2.98PV, respectively. It is clear that the CO_2 microbubbles were able to sweep out more than the normal microbubbles. For example, the oil recoveries were identified as 56.04% and 45.12% after 1.0PV injection of CO_2 in the specimen. The case of microbubbles is about 10.92 % point higher than the case of normal bubble.

Keywords: X-ray CT, CO2 microbubble, CO2 normal bubble, heterogeneous rock

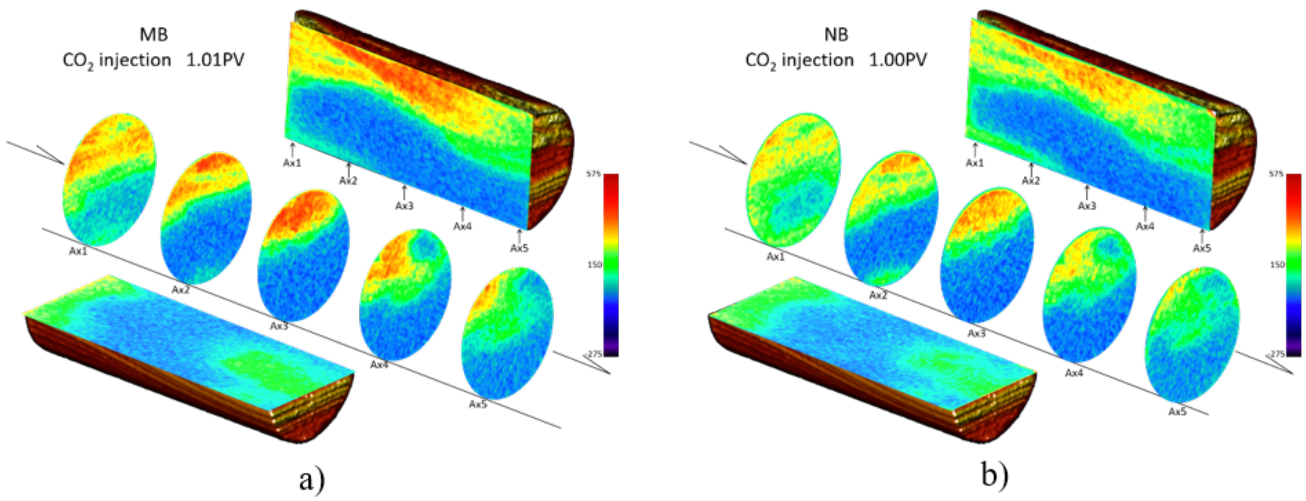

Figure. X-ray CT differential images of CO_2 microbubble and normal bubble flooding in the Sarukawa sandstone a) after 1.01PV(pore volume) injection of CO_2 microbubbles, b) after 1.00PV injection of CO_2 normal bubbles

Preliminary evaluation on geochemical impacts to rock's sealing performance

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Geologic CO_2 storage supposes that a caprock prevents the leakage of CO_2 to the ground surface. The sealing performance of caprocks is controlled by permeability k and threshold pressure P_c^{th}. Many efforts have been undertaken to measure these parameters for rocks obtained from actual storage sites. However, a caprock would be exposed to acidified circumstances over a long period of time. Our knowledge related to the sealing performance of such reacted rock is restricted. Therefore, this study aims to assess quantitatively the change of the sealing performance caused by geochemical reactions.

Six different kinds of rocks, i.e., three mudstones from Namihana Formation, Ohara Formation, and Ichishi Group, and the marlite from Itsukaichi-machi group, and two sandstones of Otomari foraminiferal sandstone and the coquinite from Haizume Formation, were collected from various outcrops located in Japan. These rocks were formed into a cylinder solid, with respective diameter and height of about 14 and 10 mm. Batch-type reaction experiments were done at 40°C in deionized, distilled water using a supercritical CO_2-water reaction system. A constant CO_2 pressure of 10 MPa was maintained for four weeks at a maximum. After 1, 2, and 4 weeks, the system was opened to extract rock samples. Then, k and P_c^{th} of each sample were measured using a capillary pressure measurement system.

Results revealed that the degree of geochemical impacts strongly depends on rock types. Hydrological properties of Namihana and Ohara mudstones, and Haizume coquinite, were unchanged during 4 weeks. In contrast, other three rocks reduced their sealing performance by increasing permeability and decreasing threshold pressure. In fact, Ichishi mudstone and Itsukaichi-machi marlite produced numerous cracks after reactions. Therefore, their hydraulic changes were not caused by geochemical reactions. Consequently, geochemical reactions did damage solely to Otomari foraminiferal sandstone. Here, it is generally expected that rocks containing carbonate minerals would produce leakage paths of CO_2 because carbonates' dissolution rate is generally high. However, results showed no correlation between carbonate amount and hydrological changes. This means that mineral reaction is restricted by rock's internal structure on a microscale. In the presentation, the relationship between geochemical reactions and hydraulic properties will be discussed along with the information about chemical compositions of leached components and pore throat size distributions.

Keywords: Geologic CO2 storage, Sealing performance, Geochemical reaction, Carbonate minerals, Caprock, Threshold pressure

An option for marine monitoring at offshore CO_2 storage sites: observing pCO_2 in the sea

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Carbon dioxide (CO_2) capture and storage (CCS) is a promising option to reduce CO_2 emissions and consequently to mitigate global warming. Since reservoirs capable of storing CO_2 stably are selected, the risk of CO_2 leakage is extremely low. There is, however, concern that CO_2 might leak out. To verify that CO_2 is not leaking, as well as to detect CO_2 leakage if leakage occurs, monitoring is important. In offshore storage, since leaked CO_2 would go out into the sea out of the seabed, monitoring in the sea is necessary. However, there seems to be no monitoring method that is useful in all sea areas or for all situations. In the practical monitoring, it is necessary to combine a few methods according to the situation and the sea area. Partial pressure of CO_2 (pCO_2) in the sea is one of items to monitor since pCO_2 in the sea would increase by leaked CO_2. However, it is difficult to distinguish high pCO_2 values due to CO_2 leakage from those due to natural variability in some areas. In the present study, we discuss a method to assess anomalously high values of pCO_2 using not only pCO_2 but also dissolved oxygen. As an example, we analyzed data observed in Osaka Bay. We have shown that the method using both pCO_2 and DO is effective in the eastern (innermost) part, where stratification is relatively strong throughout the year. However, the method is less effective in the western part of Osaka Bay, where water is relatively well mixed vertically due to strong tidal currents. We have concluded that observing pCO_2 and assessing it based on both pCO_2 and DO is potentially a useful option for marine monitoring although this method is not effective in all sea areas.

Keywords: offshore storage, CCS, partial pressure of CO2, dissolved oxygen, marine monitoring

