Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

HRE31-11 Room:419 Time:May 2 12:15-12:30

Liquid carbon dioxide storage beneath man-made hydrate-seal layers

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The findings by Sakai *et al.* (1990) that carbon dioxide (CO_2) hydrate occurs on the Okinawa Trough seafloor of 1,335m in depth and at a temperature of 3.8^oC stimulated the research on how to isolate the anthropogenic CO_2 from the atmosphere. Various offshore sites under the CO_2-hydrate stable conditions, *i.e.* above 4.4MPa and below 10^oC, are found in the Japan Archipelago. Above all, there are ten or more places where from the coastline the ERD well can make a direct access to the sub-seabed under the CO_2-hydrate stable conditions (Ohsumi, 2012). Sakai *et al.* postulated that CO_2 hydrate fills in the pore of the sediment right beneath the sea bottom, which can be explained by the fact that the density of $CO_2 \bullet nH_2O$ as calculated to be 1.07 ~ 1.04 g cm^{-3} corresponding to n = 7 ~ 8, is larger than that of the bottom seawater, and hence the even thin hydrate layer functions as a barrier for the underlain fluid (its estimated density is 0.92 g cm^{-3}) composed mainly of liquid CO_2 tending to leak to the bottom waters.

Koide *et al.* (1997) pointed out that the formation of CO_2 hydrate in pores and gaps, in rocks and sediments, could almost completely block the migration of fluid. CO_2 that is injected into a deep reservoir would migrate upward into cooler aquifers and eventually form a CO_2 hydrate cap. Numerous engineering studies thereafter were targeted at how such a sealing layer can be created in the CO_2 storage site. It should be noted that CO_2 hydrate exposed to the open bottom water will be dissolved easily even under the low-temperature, high-pressure stable conditions. Nevertheless, in his examination on how underwater pavement operation could realize the CO_2-hydrate storage beneath seabed, Ohsumi (2012) illustrated that a 1-m thick sediment layer would be enough to serve as an effective barrier. Since the solute CO_2 diffusion in sediment pores between the hydrate layer and the sea-bottom is rate-limiting, the seepage flux of CO_2 would be below 0.1 kgCO_2 m^{-2} per year.

There is an offshore steep slope to the Sagami Trough at the north-east coast of the Izu-Oshima Island. A 440-m isobath is near to the shoreline (the nearest point is 1.1 km offshore) and hence due to the fact that the sea bottom temperature will not exceed 10^oC throughout the year, the CO_2-hydrate stable conditions spread over the offshore bottom and its sub-seabed. The offshore geology consists of "old volcano" bodies, several hundred thousand years of age, of which volcanism is probably similar to the present volcano of the Izu-Oshima Island. Hence, we can suppose that it is composed of alternating layers of basalt lava and pyroclastic rocks. When the pores of horizontally permeable layers are filled with CO_2 hydrate, the underlain formations can hold the liquid CO_2 for storage. Ikegawa *et al.* (2012) proposed the injection method of CO_2-in-water emulsion applicable to the sedimentary layers for the purpose of enhanced recovery of methane hydrate. By their method, while avoiding hydrate blockage in the horizontal pore space flow, as shown in Figure we might be able to create the effective CO_2-hydrate seal layers with a large area coverage. A horizontal coverage of the supposed storage site could be 5$\times$1 km. When storage layers with 200-m effective thickness are selected, 10% of the effective pore volume ratio for liquid CO_2 storage gives 100 million tCO_2 as an attractive storage potential.

Ikegawa, Y *et al.* (2012) *CRIEPI Report* N11024 (in Japanese with English abstract); Koide *et al.* (1997) *Energy* **22**(2/3) 279-283; Ohsumi, T (2012) The 23rd Ocean Engineering Symposium (in Japanese with English abstract); Ohsumi,T (2013) *2013 Fall meeting Programme and Abstracts* (in Japanese) 152-154; Sakai *et al.* (1990) *Science* **248,** 1093-1096.

Keywords: man-made seal layer, CCS, hydrate seal, Izu-Oshima Island, Extended Reach Drilling, CO2-in-water emulsion

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