Risk and Benefit Analysis of Microbial Associated CO_2 Geological Storage

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Keywords: CCS, methanogenic archaea, methane production, risk analysis, environmental impact, risk and benefit

Intoroduction

Among in-situ microbes within depleted oil-gas reservoir, there are special species those produce much more methane gas in CO_2 rich environment than in CO_2 poor environment. CO_2 acts as a catalyst in the reaction. If we maintain preferable conditions for methanogenesis archaea during geological CCS, we will be able to abate emission of GHG and produce natural gas as one of natural energy resources at the same time. We named the concept as 'Microbial associated Geological CCS (Bio-CCS)'. In Bio-CCS, CO2 will be injected for two purposes: to abate GHG and to cultivate methanogenic geo-microbes. CH_4 gas will be produced later from other wells. The procedure is similar to the Enhanced Oil/Gas Recovery (EOR/EGR) operation, but in Bio-CCS, the target is production of methane out of depleted oil/gas reservoir during CO_2 abatement.

Methanogen in depleted reservoir

We examined relationship between reactions of in-situ microbial communities and CO_2 partial pressure in cultivation conditions. We collected bailed water samples those containing in-situ microbes from Yabase depleted oil-gas field in Japan. We kept containers in 55ºC, 5MPa, and measured concentrations of CO_2 and CH_4 partial pressures of the gas in the containers. As the result, we found specific species that accelerates CH_4 production rate two times faster than other methanogenic species (1). The findings initiated the Bio-CCS concept.

Feasibility study of Bio-CCS

When we consider feasibility of Bio-CCS concept, the most essential information is CH_4 produce potential. To estimate production rate, we assumed a procedure of Bio-CCS site: 1 million tons CO_2 will be injected into depleted oil reservoir in 10 years; the reservoir will be kept still for 90 years and 0.5 million CH_4 will be produced; after 100 years from the first CO_2 injection, CH_4 production will be started. We developed a basic geological model of Bio-CCS process on CHEM-TOUGH simulator, and implemented microbial activities and CCS process into it. We applied measured value in Nagaoka and Yabase as mineralogical properties of depleted reservoir. We assumed a fluid flow model; residual oil is a part of matrix and it will not move; fluid will flow in the rest, 0.1 real pore space. Then we estimated CH_4 production rates and other masses' distributions (2). Given these conditions, estimated CH_4 production rates were about 1/10 – 1/100 of injected CO_2, after 100 years of first injection.

Based on result of numerical calculations, we developed hazard scenarios by way of literature survey and statistical analysis of accident statistics. Then we applied the hazard scenarios to the assumed Bio-CCS procedure.

Results

As the result, the preliminary risk assessment assures that the Bio-CCS process will be safe. If it happens any leaking accidents, most impacts on peripheral area of Bio-CCS site will be negligible.

Refining the model for numerical simulation and Bio-CCS site evaluation system, we developed prototype of Microbial associated Geological CCS (Bio-CCS) site evaluation system.

References:

1. D.Mayumi,et.al: Nature Communications, vol.4, pp.1-6 (2013)
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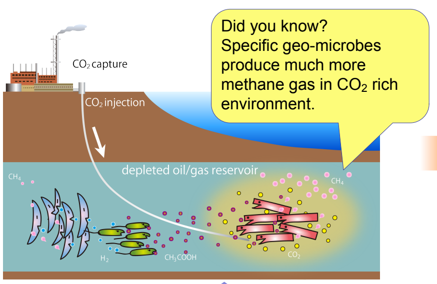
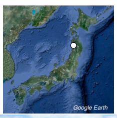
Utilization of CO_2 and In-situ Methanogen



Methanogen in depleted oil reservoirs



Depleted Oil Reservoir
Depth: 1,000-1,300 m
Temperature: 53-65°C
Pressure: 5 MPa

1000 ml container
- bailed water 800ml
- purge gas 200ml

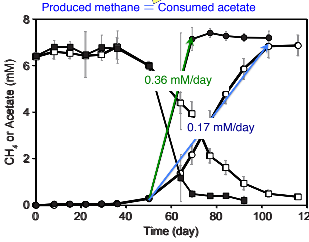
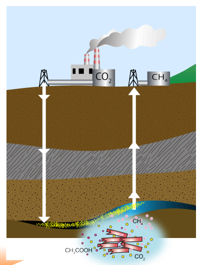


Fig. Rate of methanogenesis and CO_2 concentration.

Mayumi *et al.*, 2013, *Nature Communications*

Conceptual 'Bio-CCS' Plant

	Site A	Site B
Depleted oil reservoir	Depth: 1000 – 1300m Pressure: 5Mpa Temperature: 55℃	
CO_2 capture	Amine	
CO_2 source	Thermal power station Oil-gas well	
CO_2 transportation	Gas pipe line CO_2 lq. ground transportation	
CO_2 injection rate	1 – 10^5 ton /year	
Condition of CO_2	Super critical CO_2	
Injection	1 – 100 years	
Methane producing rate*	0.36 ± 0.04 m mole/day/L-water	



Estimation of methane production rate in Bio-CCS process

Table Assumptions for Formation fluids

Formation water

	m mol/l
Na +	183
Cl −	132
Mg 2+	0.1
K +	0.8
Ca 2+	0.1
NH4 +	1.4
HCO3 −	39.6
SO4 2−	0.5

Rock matrix

g/mol			vol %
60.08	SiO_2	Quartz	29.3
278.34	$KAlSi_3O_8$	K-feldspar	13.5
278.21	$CaAl_2Si_2O_8$	Anorthite	9.8
262.22	$NaAlSi_3O_8$	Albite-low	20.2
366.04	$Ca_{0.165}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	Ca-montmorillonite	29.2
100.09	$CaCO_3$	Calcite	0.2
172.17	$CaSO_4 \cdot 2H_2O$	Gypsum	0.1
258.16	$Al_2(Si_2O_5)(OH)_4$	Kaolinite	0.0

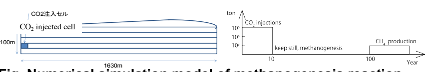
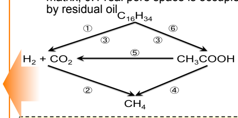


Fig. Numerical simulation model of methanogenesis reaction.

CO_2 is injected in 10^5 ton/years rate for 10 years. Then stop injection and leave it still for 90 years.

0.2 real pore space for reservoir matrix; 0.1 real pore space is occupied by residual oil



$$4C_{16}H_{34} + 30H_2O + 34CO_2 \leftrightarrow 49Ac^- + 49H^+$$
$$49Ac^- + 49H^+ \leftrightarrow 49CO_2 + 49CH_4$$
$$4C_{16}H_{34} + 30H_2O \leftrightarrow 15CO_2 + 49CH_4$$

Fig. Reaction summary for methanogenesis from crude oil during CO_2 injection (Dolfing, J et al.)

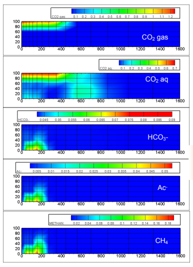


Fig. Distribution of masses (elapsed time = 74.2 years)

Sakamoto *et al.*, 2014, 2015, *MMIJ*

Evaluation of Risk and Benefit

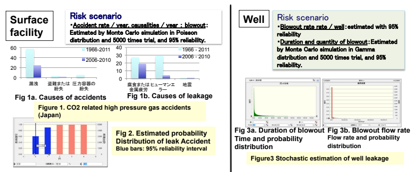


Table1 Estimated yearly Bio-CCS accident rates: Handling 10^5 ton CO_2 and 10^3 CH_4 per year. (95% reliability)

	accident / year / CO_2 10^5ton	accident / year / CH_4 10^3ton
Accident rate	0.5	0.0
(leak accident rate)	(0.2)	(0.0)
Fatality rate	0.0	0.0
Serious accident rate	0.0	0.0
Slight accident rate	0.0	0.0

most likely

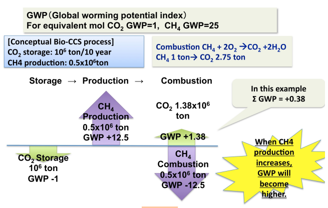
Table2 Estimated Bio-CCS well blowout (95% reliability)

	Estimated
Frequency	0.005 times / well
Duration	5 hours / 1 blow out
Flow rate	100 ton / 1 blow out

Table Impacts of risk scenarios

	CO_2	CH4
Leakage	All injected CO_2/A few hours All injected CO_2/year 1% / year	All injected CO_2/A few hours All injected CO_2/year 1% / year
Handling	Injection rate ~ 10^5 ton/year	Production rate ◎ CO_2 is injected from one well. ～100 − 10 ton / 100 years ◎ multiple wells, optimized injection method
Impact to ambient air	All CO_2/A few hours No impact on residential area All injected CO_2/year 1% / year	All CO_2/A few hours No impact on residential area All injected CO_2/ year 1% / year
GHG gas abatement	CO_2 quantity in reservoir will increase: injected CO_2 + produced CO_2	Bio-CCS will abate less CO_2 than CCS Creation of natural energy resources (= produce GHG gas) -> different from usual CCS
Impact to peripheral area	Will increase relating to handling quantity	Will increase relating to handling quantity

Figure Abatement of CO2 Emission?



Prototype Bio-CCS Site Evaluation