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Effects of stratigraphic heterogeneity on upward migration of CO_2 in saturated porous media: Laboratory experiment and numerical simulation

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1-4 NOVEMBER GSA 2015 Baltimore, Maryland, USA

Abstract

GCS (Geologic Carbon Sequestration) is considered as primary technique for reducing the greenhouse gas emission, particularly carbon dioxide. Many countries are developing their techniques for capture, storage, transportation as well as MMV (Measuring, Monitoring and Verification). In the view of MMV, early detection of CO_2 leakage is one of the main considerations. Before constructing the shallow subsurface monitoring system using sensors near the GCS site or the buried pipeline, it is important to choose monitoring point where leaked CO_2 might be passed. Naturally, subsurface media might have stratigraphic heterogeneity such as layer or lenses, and it has potential to affect the upward migration of CO_2.

To identify CO_2 leakage potential according to different stratigraphic heterogeneity, 2-D laboratory experiment was conducted using glass beads and transparent acrylic tank for visualization. The experiment conditions of embedded layer had seven different grain size ranges and each condition had slightly different physical properties such as capillary pressure and permeability. In homogeneous condition with which the layer has same grain size with background, the upward movement of CO_2 occurred all the way to the top surface. As difference of grain size between background and layer increases, upward migration through the layer gradually disappeared. The coarser layer had relatively lower capillary pressure and higher permeability compared to neighboring regions and it became a preferential flow path of CO_2. Whereas, the finer layer which had higher capillary pressure and lower permeability than background region acted as a barrier preventing from CO_2 rising. Numerical simulation using TOUGH2 was performed to generalize the previous experiment results and to apply more detailed conditions. The simulation results showed that not only the CO_2 saturation but also the position where the CO_2 plume accumulated were affected by the layer conditions.

These results of both laboratory experiment and numerical simulation suggest that the geological stratigraphic heterogeneities should be considered when selecting monitoring point to achieve the successful detection of CO_2 leakage.

Introduction

- One of the potential risks of geologic carbon sequestration (GCS) technology is the possibility of CO_2 to leak out to the shallow aquifer system and, eventually, to impact the groundwater quality.
- Implementation of a measurement, monitoring and verification (MMV) plan is essential for the sustainability of the GCS scheme (Rock et al 2014).
- Several cases related to failure for CO_2 leakage detection in artificial leakage experiment caused by the presence of heterogeneity are reported (Cahill and Jakobsen, 2013; Barrio et al., 2014).

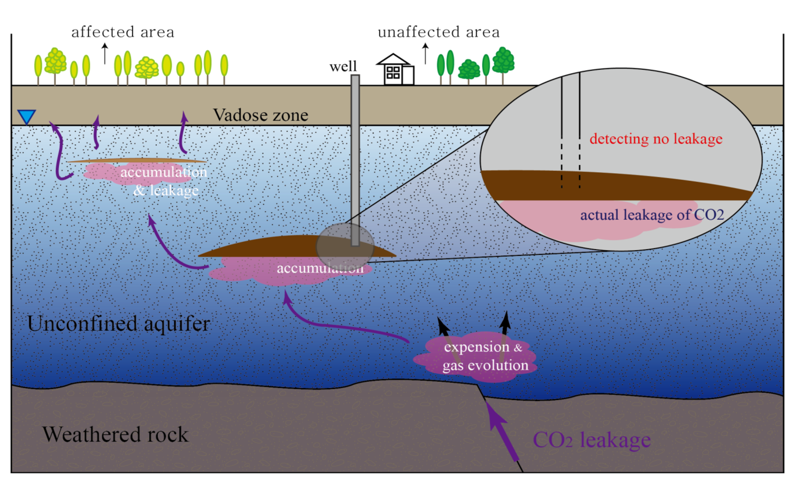


Fig. 1 Conceptual illustration of CO_2 leakage in a shallow aquifer

❖ Objectives of this study

- Understand the basic information about the movement of gaseous CO_2 in the saturated porous medium.
- Characterization of the heterogeneity role on the migration of CO_2 in shallow aquifer system.

To study the effects of stratigraphic heterogeneity on gaseous CO_2 upward migration and flow pattern around the heterogeneous layer.

Experiment

❖ Experimental set up & conditions

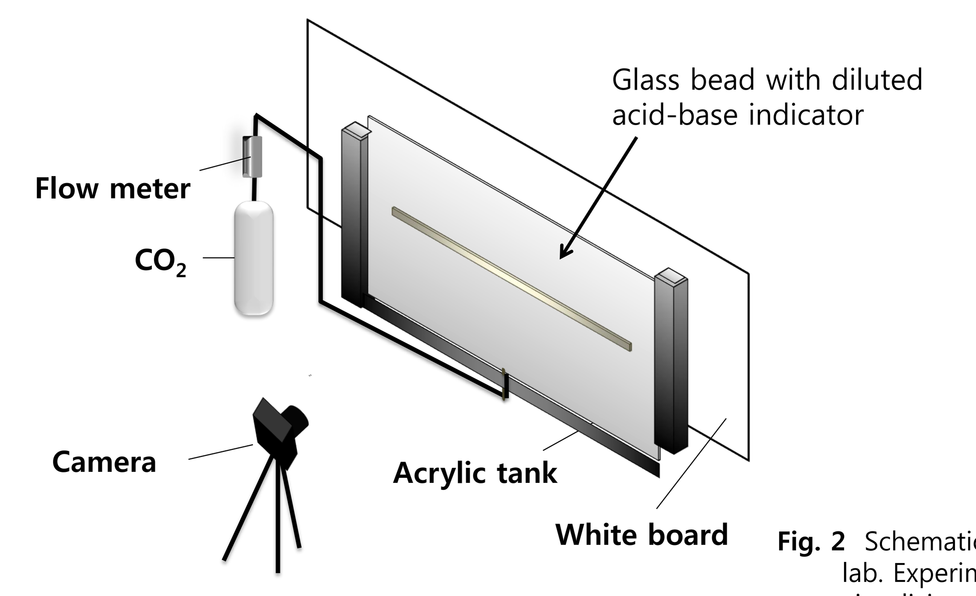


Fig. 2 Schematic diagram of lab. Experiment for visualizing CO_2 flow path

➢ Glass beads properties

No.	Description	D_{50} [mm]	Hydraulic Conductivity (K) [cm/s]	Intrinsic permeability (k) [cm^2]	Ratio of k*
1	Fine layered	0.303	0.081	8.25E-07	2.80
2		0.428	0.110	1.12E-06	2.06
3		0.550	0.145	1.48E-06	1.56
4	Background	0.875	0.226	2.31E-06	1.00
5	Coarse layered	1.185	0.239	2.45E-06	1.06
6		1.325	0.243	2.48E-06	1.07
7		1.475	0.248	2.54E-06	1.10

❖ Results

$$\text{Ratio of } k = \frac{k_{coarser\ media}}{k_{finer\ media}}$$

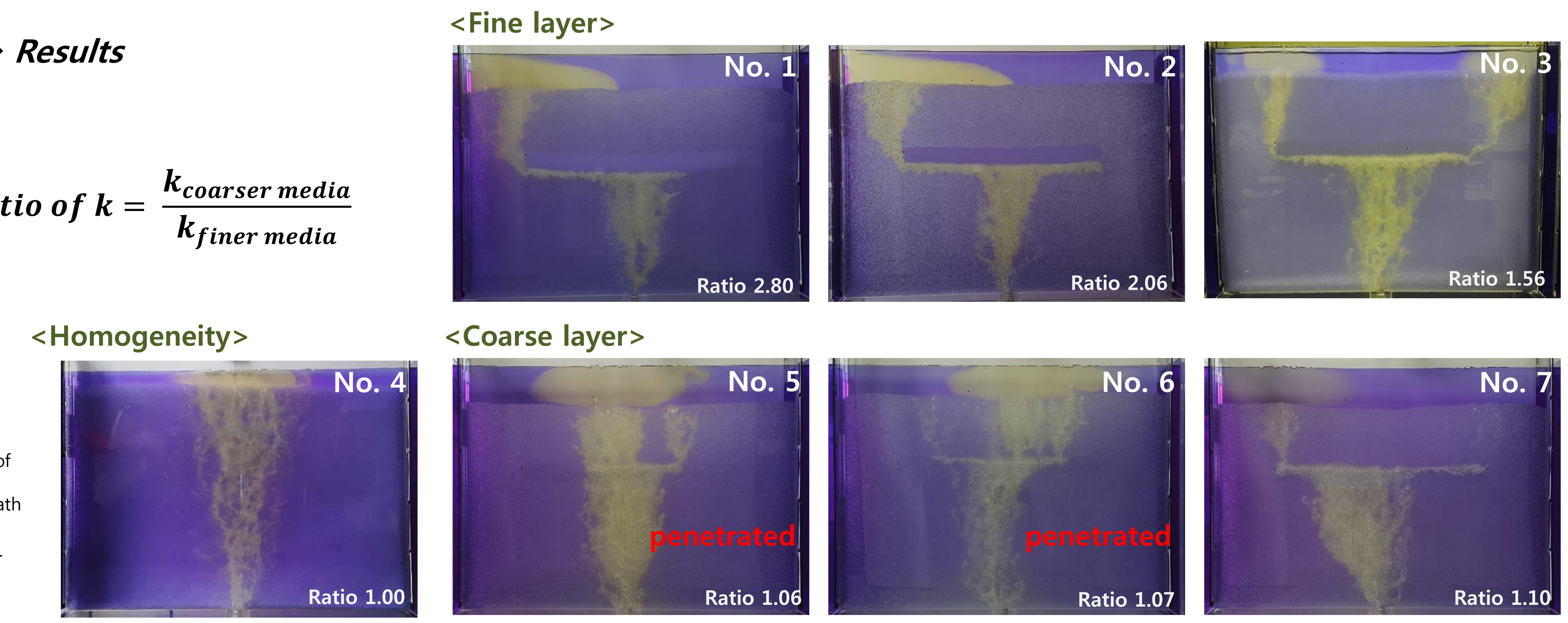
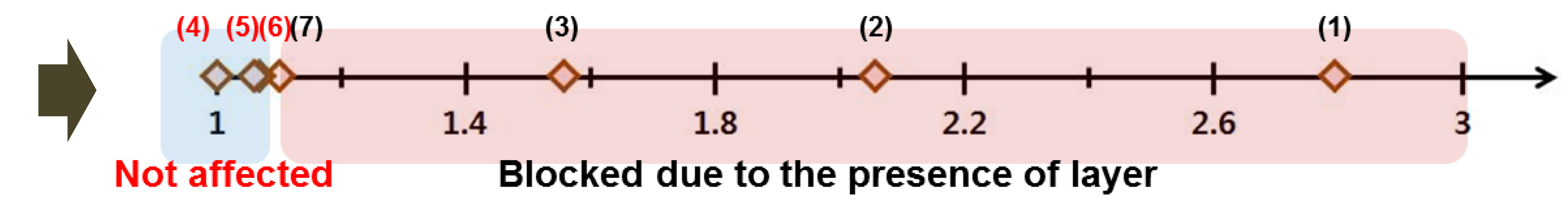


Fig. 3 Different flow path in different layered condition (background: purple, CO_2 path: yellow)



2-D Numerical simulation

❖ Simulation condition

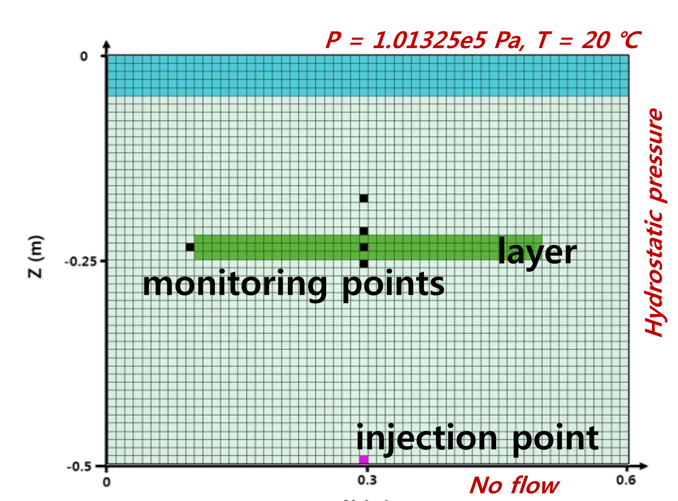


Fig. 4 Idealized model system showing discretization boundary conditions

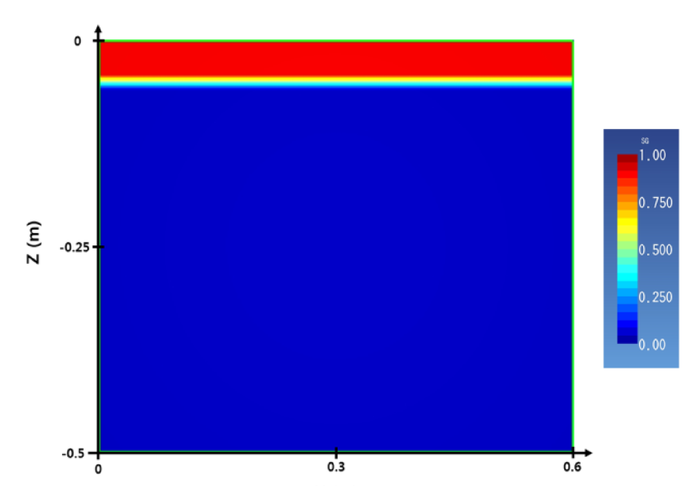


Fig. 5 Steady-state gravity-capillary equilibrium for initial gas concentration

- Simulation time: total 800 sec (injection 300 + after stop 500)
- CO_2 injection rate: 7.664e-7 kg/sec (= 25 cm^3/min)

➢ Input parameter

material	Isotropic Permeability (k) [cm^2]	Ratio of k	Porosity (φ)	van Genuchten parameter				
				λ	S_{lr}	S_l	S_{gr}	α [m^{-1}]
Background	2.31E-06	1.00	0.35	0.580	0.29	1.00	0.05	6.900E-4
Coarse layer*	3.80E-06	1.65	0.35	0.451	0.25	1.00	0.05	1.460E-3
Fine layer*	3.00E-07	7.70	0.35	0.697	0.32	1.00	0.05	3.679E-4

* Porter et al., 2014

❖ Results

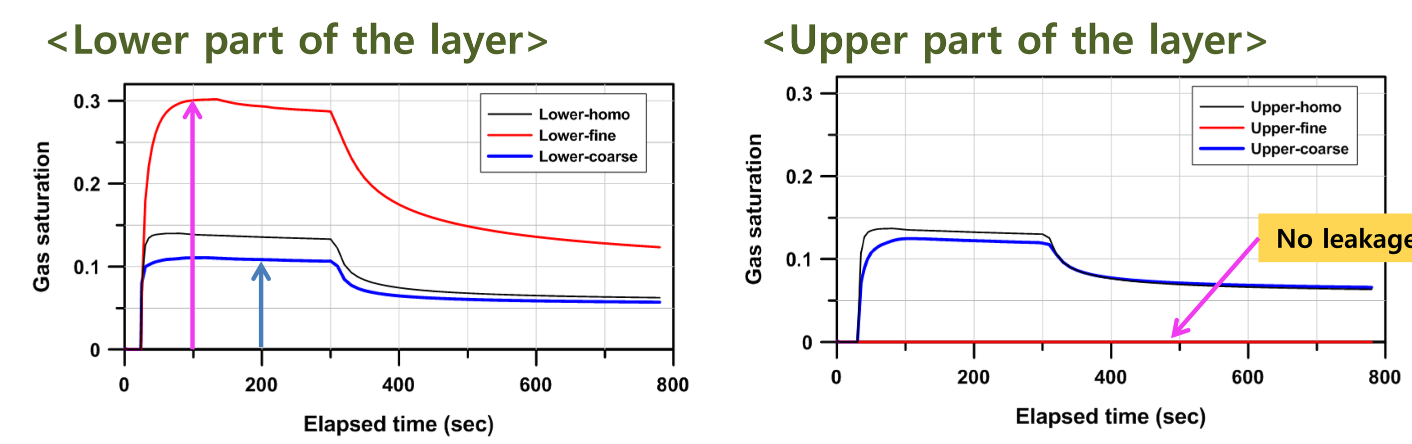


Fig. 6 Gas saturation variation at the same monitoring point (Left: lower part of the layer; Right: upper part of the layer)

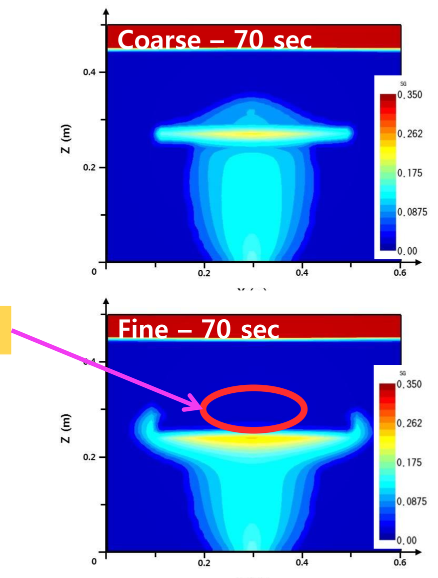


Fig. 7 Contour plan view in different layered condition at 70 sec

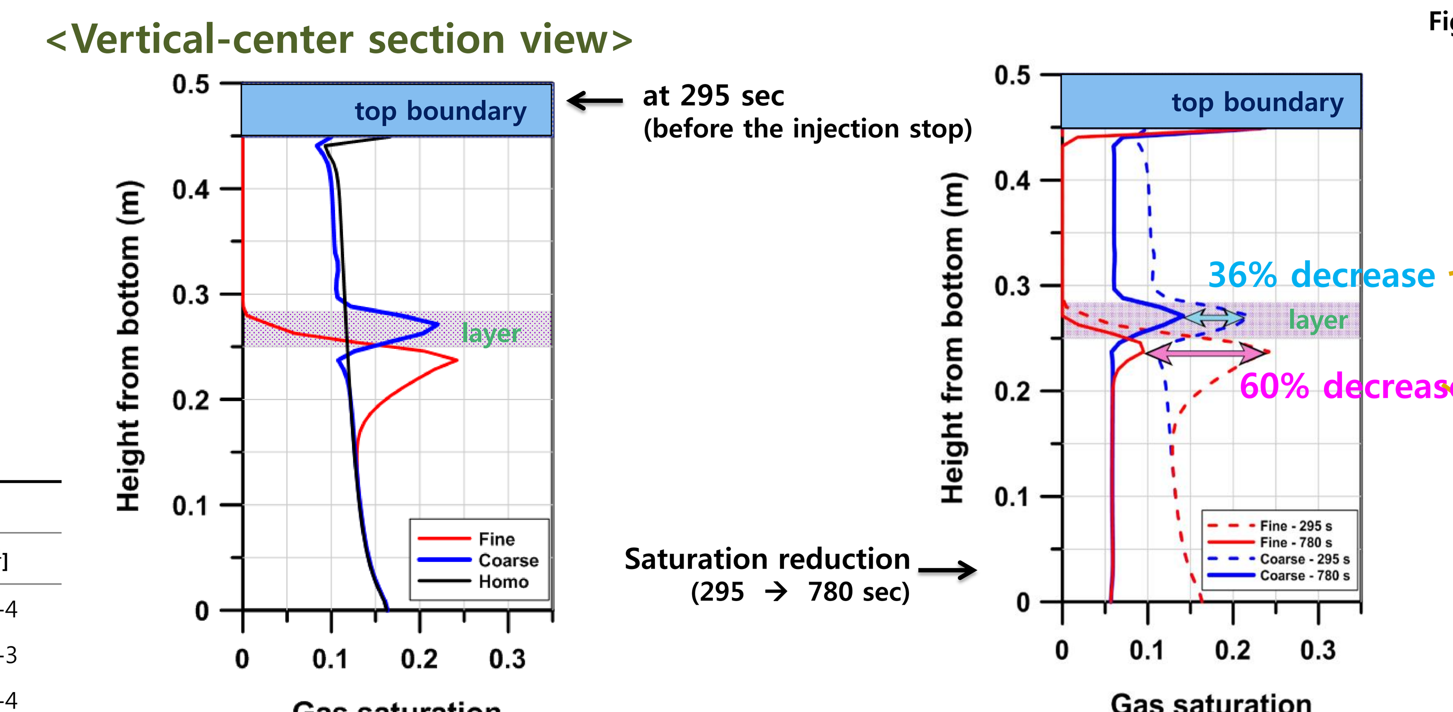


Fig. 8 Vertical profiles of gas saturation at the center of domain

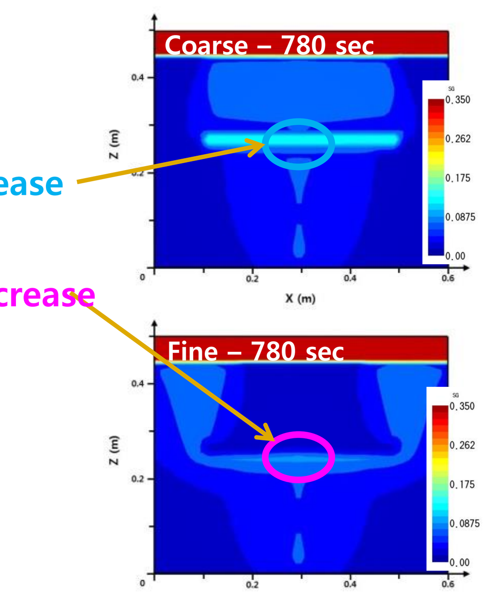


Fig. 9 Contour plan view in different layered condition at 780 sec

Summary and conclusion

- Laboratory experiments and numerical simulations were conducted to study the effects of stratigraphic heterogeneity on gaseous CO_2 migration.
- The embedded fine layer acted as a capillary barrier on the upward migration of free CO_2 which migrated around the layer, and eventually left another place.
- The intercalated coarse layer became not only preferential path of free CO_2, but it also had high capacity of retaining gaseous CO_2.

References

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Acknowledgement: Financial support was provided by the "R&D Project on Environmental Management of Geologic CO2 Storage" from the KEITI (Project Number: 2014001810003)