

Effect of lower permeability top layer in shallow seabed for CO₂ hydrate formation

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ABSTRACT

The prospect of CO₂ storage in the form of gas hydrate is suggested in sites such as permafrost bedrock, natural gas reservoirs, and under the seafloor. CO₂ hydrate formation beneath the seafloor is a suggested option due to its high storage volume and minimal environmental impact. This study focuses on the CO₂ hydrate formation trend in a shallow seabed at a depth of 600m or less, with a low permeability soil layer on top of the seabed. As opposed to previous literature that used CO₂ density to prevent CO₂ from escaping the seabed, the effect of flow obstruction caused by the lower permeability of the site is investigated. The tendency of CO₂ hydrate formation beneath the layered seabed is examined numerically using a thermal-hydraulic-mechanical model implemented with FLAC 2D. The existence of a lower permeability top increases formation amount, even when the top layer has a discontinuity. This study supports the idea of expanding the range of acceptable sites for CCS through CO₂ hydrate formation.

1. INTRODUCTION

Gas hydrates are crystals formed when certain gases are trapped between hydrogen-bonded water molecules under low temperature and pressure conditions. First discovered in laboratory settings by Davy in the early 19th century and studied as man-made chemical compounds, gas hydrates began to be recognized from an engineering perspective in the 1930s when they were suggested as a cause of poor gas pipe flow in the natural gas industry. Since then, natural gas hydrates have been discovered in permafrost and submarine basins, and methane hydrates in particular have been actively explored as a new energy resource.

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As an alternative to producing gas from naturally occurring methane hydrates, methods for storing carbon dioxide underground as gas hydrates has been suggested to suppress atmospheric oxygen emissions. House et al (2006) proposed the possibility of subsea storage of carbon dioxide by considering a gas hydrate formation zone along with a neutral buoyancy zone, where the density of carbon dioxide is lower than that of seawater under low temperature and high pressure at depths of more than 3 km. Numerical simulations of carbon dioxide hydrate formation for subsea storage purposes have considered frozen ground, the seafloor, and rock layers as candidate storage areas.

However, the formation conditions for carbon dioxide hydrate are low - around 5 MPa at room temperature – and can be met in the shallow seabed of 500 m to 1 km, which does not reach the NBZ. This raises the possibility of relatively accessible low-depth seabed storage of carbon dioxide hydrate.

2. T-H-M FORMATION MODEL FOR CO₂ HYDRATE

2.1 Formation Model

The model proposed by Kim and Bishnoi in 1987 represents the gas hydrate formation/dissociation rate as the difference in fugacity between the three-phase equilibrium and the gas phase. Uddin et. al (2008) simulated gas hydrate formation by considering the kinetic reaction at the surface where gas hydrate is formed as Eq. (1)

$$\frac{dc_h^{(f)}}{dt} = k_f A_f \rho_e \exp\left(-\frac{E}{RT}\right) \left(\frac{1}{K(p,T)-1}\right) \quad (1)$$

Where k_f is the gas hydrate formation rate, A_f is the gas hydrate formation area, E is the activation energy, and K is the ratio between the equilibrium pressure and the gas pressure.

3. FORMATION IN LAYERED GROUND

3.1 Model Settings

The amount of carbon dioxide hydrate formation was compared in two models with a clay layer on top of a sand layer. The first model has a 13.3 meter thick clay layer on top of the sand layer. The second model has the same top 13.3 meters of clay as the first, but with a 9-meter wide sand layer directly above the injection well. (Fig. 1) The physical parameters used are shown in Table. 1

In this case, the HFZ of the two models and the base model are the same, but the difference in pore pressure induced at the top leads to differences in injection pressure and total injection volume (Table 2, Figure 2). Although the difference between the two models is small, it can be seen that the injection volume and total formation volume are 0.2% and 0.3% larger, respectively, for the intact clay layer with higher injection pressure. This is an insignificant difference compared to the total injection volume and formation volume, indicating that even after carbon dioxide propagation to

the seafloor and formation of carbon dioxide hydrate in the clay layer, there is no significant degradation of formation due to high permeability "holes" in the clay layer.

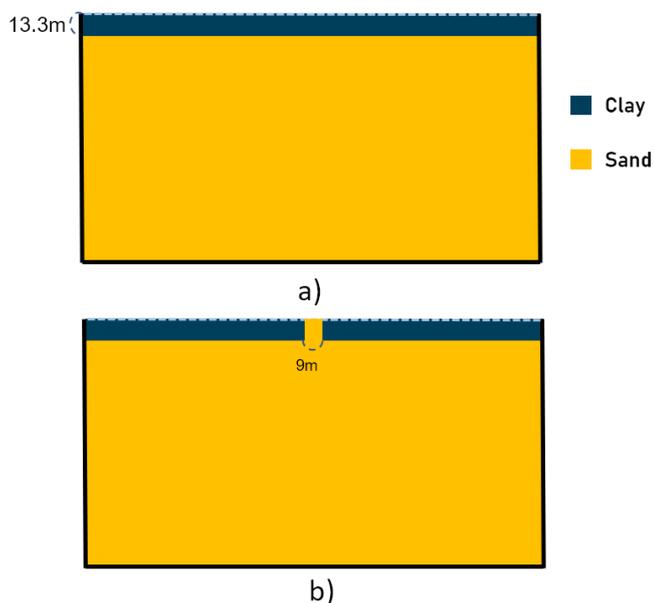


Fig. 1 Model structure of top cases

Table. 1 Ground parameters for model

Geological conditions		Thermal properties				
Hydrostatic pressure at site (MPa)	4.59	Conductivity (W/mK)		Specific heat (J/kg K)		
		S	1.45	Grain	0.58	
Temperature at site (K)	278	M	1.00	Hydrate	2090	
		Water	0.58	Water	4182	
Mechanical Properties				Gas	2200	
Dry density (kg/m ³)		Bulk Modulus (MPa)		Formation heat (kJ/mol)		
S	665.5	S	27	60		
M1	465.5	M1	17			
M2	575.5	M2	20			
M3	605.5	M3	22			
Hydraulic properties						
Porosity	sand	M1	M2	M3	van Genuchten parameters	
	0.45	0.76	0.67	0.63	P ₀ (kPa)	1
Permeability (D)	300		0.2		a, b, c	0.336, 0.5, 0.333

Table. 2 CO₂ injection and CO₂ hydrate formation for each case

	Injection Pressure	Injection Volume	Total Formation
No Top	100%	100%	100%
Full Top	+ 59.5%	+ 1.22%	+ 6.98%
Top with Hole	+ 59.3%	+ 0.90%	+ 6.77%

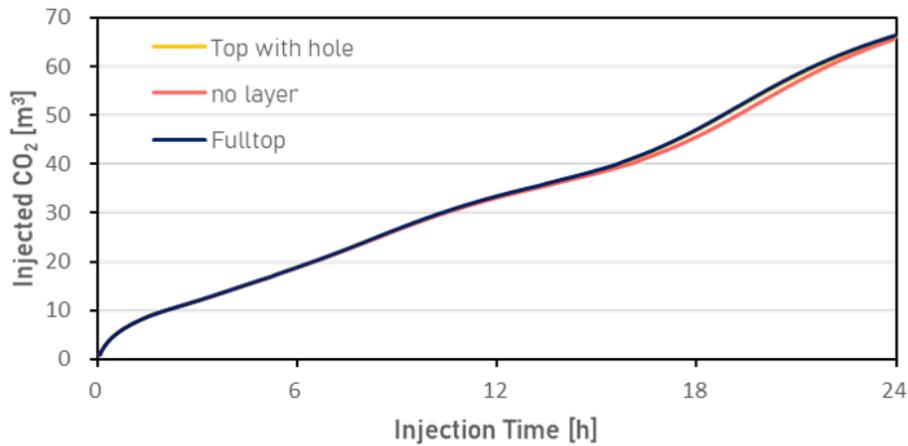


Fig. 2 Injection volume comparison for each case

3. CONCLUSIONS

Ground conditions, especially initial permeability, greatly affect the propagation of carbon dioxide, which in turn affects the formation of carbon dioxide hydrate. As the pore pressure increases significantly without resolving, it is essential to design the injection strategy, including the injection rate and limit pressure, to avoid the formation of carbon dioxide hydrate near the injection port and cause blockage. On the other hand, the upper low permeability layer is not affected much by its continuity and has a positive effect on the amount of carbon dioxide hydrate formation, but a sufficiently large sandy soil layer is required to reduce the flow of carbon dioxide and increase the amount of formation.

REFERENCES

House, K. Z., Schrag, D. P., Harvey, C. F., & Lackner, K. S. (2006). Permanent carbon dioxide storage in deep-sea sediments. *Proceedings of the National Academy of Sciences*, **103**(33), 12291-12295.

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Uddin, M., Coombe, D., & Wright, F. (2008). Modeling of CO₂-hydrate formation in geological reservoirs by injection of CO₂ gas. *Journal of Energy Resources Technology*, **130**(3).

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