Synergy in combining CCS and Geothermal energy production: a simulation study

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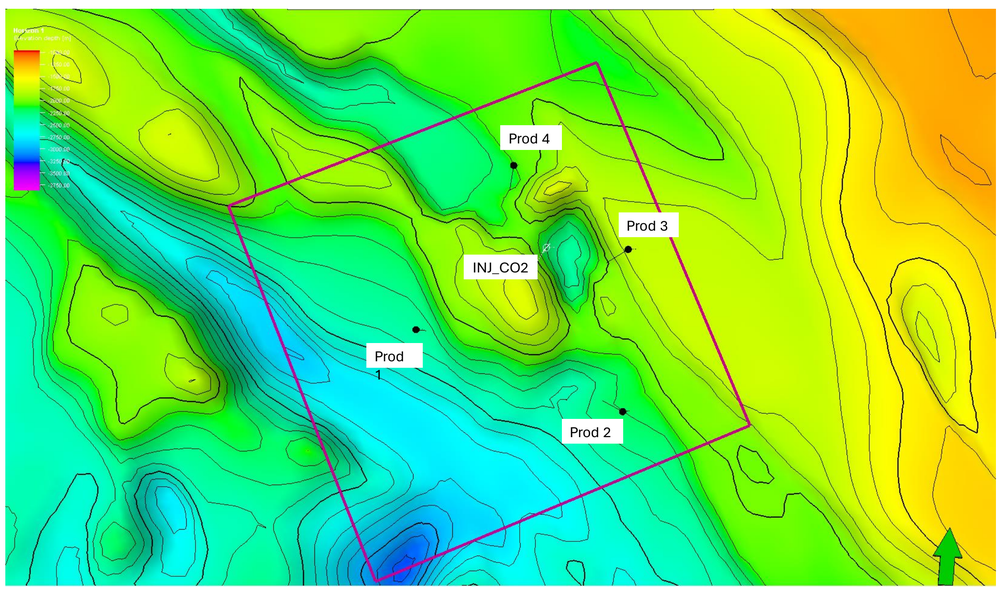
Introduction

The main subsurface risks in CCS include wellbore failure, CO_2 leakage, fault reactivation, and seal failure, which typically result from pressure increases due to injecting new fluids into the formation. Pressure pulses propagate faster and wider than the CO_2 plume, making controlling pressure increase in the storing reservoir crucial for storage efficiency and safety in CCS projects.

This study aims to assess the novel idea of "combining CCS and geothermal energy production" [1] to reduce the risks of pressure increase. It investigates the effect of geothermal wells, water production rate, well placement, and wettability on pressure pulse, CO_2 plume migration, trapping mechanism and changes in leakage risks

Methodology

The reservoir simulations of various injection and production scenarios in the Gassume formation, a potential CO_2 storage site in Denmark, were conducted using the Eclipse software's Black Oil simulator (E100). The results were thoroughly analyzed using Petrel and Python. In the simulations, the oil and gas phases are represented by Brine and CO_2, respectively. Four water wells with fixed locations and one or two CO_2 injection wells were defined. A pressure increase limit of 1 bar was set on the boundary of a polygon surrounding the Vedsted anticline and the wells to control pressure. To ensure detailed investigation, local grid refinement was implemented.



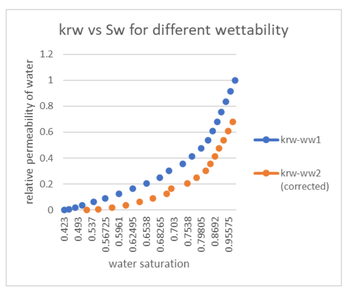
A screening criteria was developed for selecting well locations, considering parameters that can affect the performance of the CCS project and water production. The "Linear Max" method was utilized for linearization, and parameters were weighted based on their importance on storage efficiency.

Parameters	Wells in different cases				weights
	INJ_CO2	INJ2_CO2	INJ3_CO2	INJ4_CO2	
Regional pressure	0.15	0.08	0	2	2
Gas in place	6.14	6.14	10	0	10
Maximum BHP	0	10	6.76	5.6	10
Cumulative gas production	0.99	1	0	1	1
Cumulative water production	1.92	1.97	0	5	5
Average	1.84	3.83	3.35	2.72	

Based on this screening two other scenario were built and studied;

1) Best wells scenario; containing wells INJ2_CO2 and INJ3_CO2 (Case 6)
2) Worst wells scenario; containing wells INJ_CO2 and INJ4_CO2 (Case 5)

To study the effect of wettability, another wetting condition was defined by shifting the saturation points by 0.1 in the Krw vs Sw curves.



to study the trapping mechanisms, two function were defined :

$$STI = \frac{Total\ volume\ of\ solution\ gas\ in\ place}{cumulative\ volume\ of\ gas\ injected}$$

$$RTI = \frac{Total\ volume\ of\ free\ gas\ in\ place}{cumulative\ volume\ of\ gas\ injected}$$

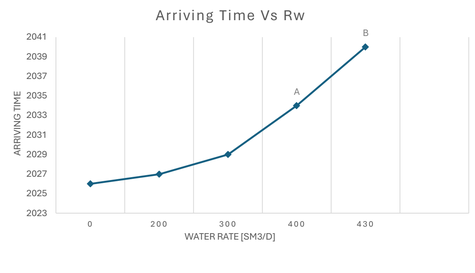
8 different cases were simulated to analyze sensitivity to the presence of geothermal wells, production rates, well placement, and wettability.

Case	Injection Rate	Production Rate	No. injection wells	wettability alteration
	[SM^3/d]	[bbl/d]		
Base Case	7,40E+05	-	1	NO
CASE1	7,40E+05	200	1	NO
CASE2	7,40E+05	400	1	NO
CASE3	7,40E+05	500	1	NO
CASE4	7,40E+05	600	1	NO
CASE5	3,70E+05	400	2	NO
CASE6	3,70E+05	400	2	NO
CASE7	3,70E+05	400	2	Yes

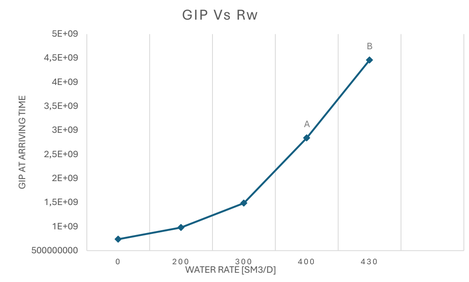
Results

1. Effect of water wells

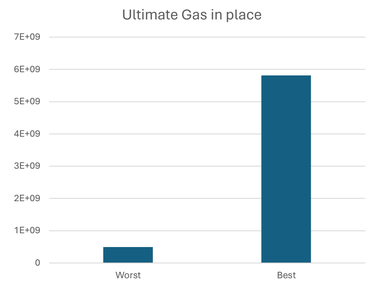
Geothermal water production wells can **extend** the injection time by more than **17 years** by delaying the arrival time of the 1-bar pressure increase pulse at the boundaries.

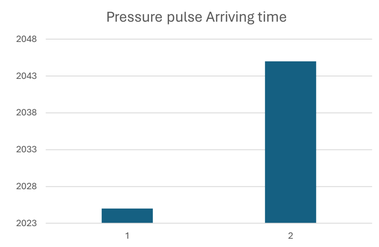


The relationship between GIP and R_w is exponential. Increasing water production by **30 M^3/d** (A to B) resulted in a **37%** increase in GIP volume.



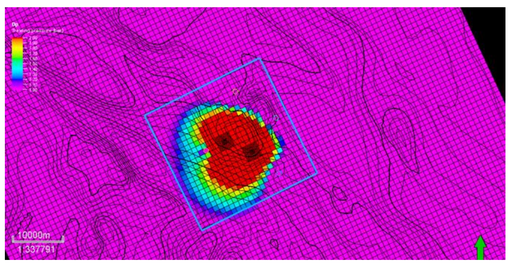
2. Effect of Well placement



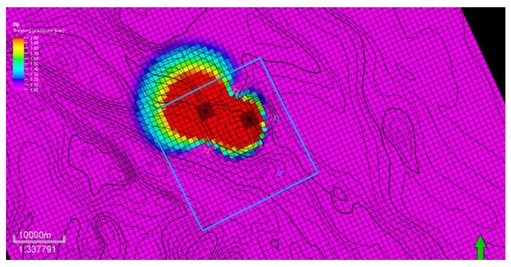


Optimal well placement (best wells) increased the storage capacity of the site (Gas in Place) by **10.7 times** compared to the worst-case scenario considering all the parameters in screening criteria.

Compared to the worst case, the pressure increase wave is more controlled in the best-case scenario and as a result, pressure remains inside the polygon for more times and makes it possible to inject a higher amount of CO_2.



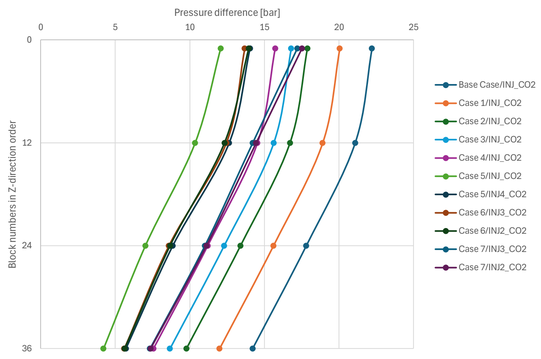
Pressure increase after 40 years (Best Wells)



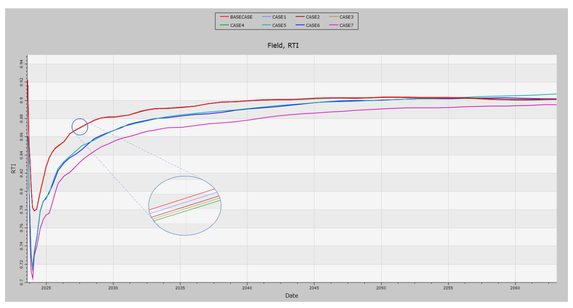
Pressure increase after 40 years (Worst Wells)

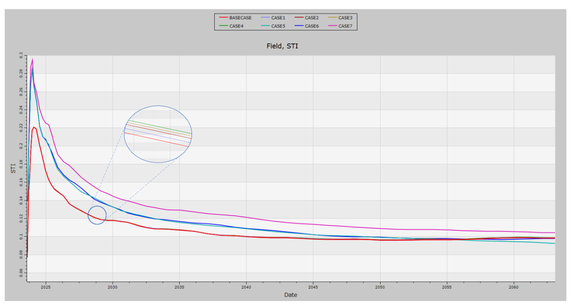
3. Reducing Risk of Leakage

In the **all cases** including geothermal wells the pressure is lower in the near surface area, this leads to **lower risk** of exceeding capillary threshold pressure, caprock and wellbore failure. In the water wetted condition (case 7) due to the higher water saturation and capillary pressure the pressure increase is higher compared to the less water wetted condition (case 6)



4. Trapping mechanisms and Safety of the storage

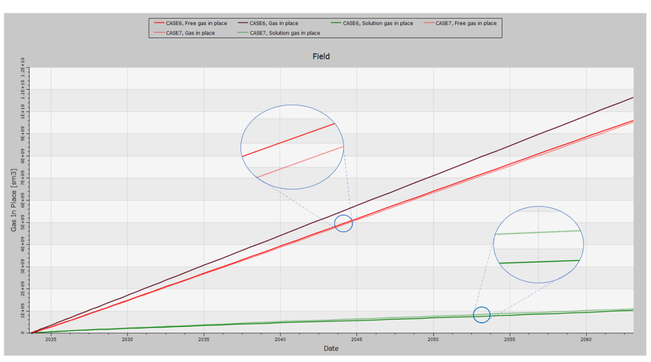




The safety of storage increased by altering the trapping mechanism. Adding geothermal wells reduced the RTI (fraction of gas stored by structural and residual mechanisms) and increased the STI (fraction of gas stored solution mechanism).

5. Effect of wettability

The total amount of gas in place **did not change** but the **trapping mechanism changed**. By increasing water wetness, the amount of solution gas and free gas increased and reduced respectively.



[1] Nielsen, C.M. and Frykman, P. 2011. Regional model development and study of pressure propagation. Energy Procedia (TCCS-6).