Fate of CO_2 during CO_2-Enhanced Oil Recovery

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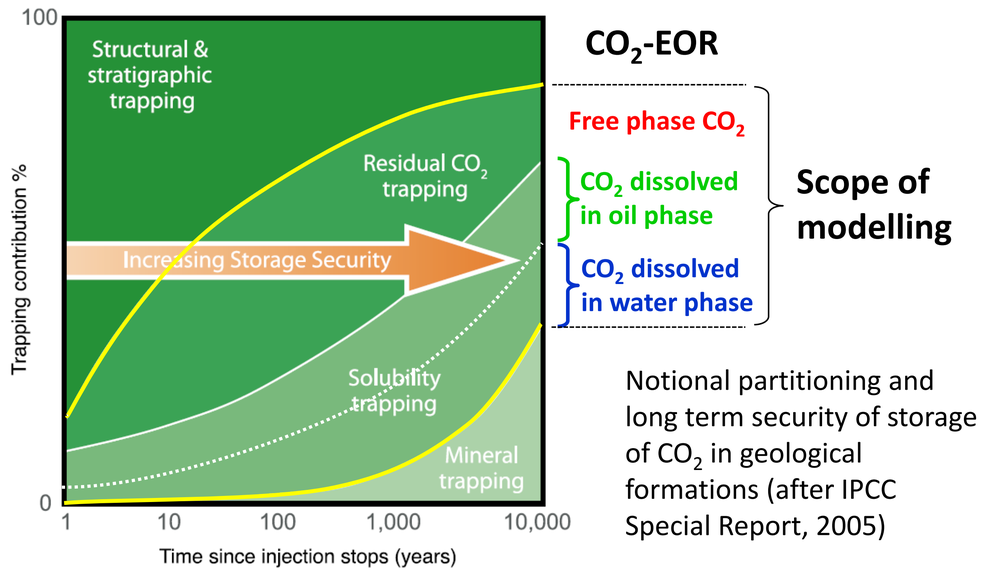
Introduction

Solubility trapping in formation fluids is one of the mechanisms whereby CO_2 can be sequestered in geological formations. Unlike saline aquifers, potential storage in hydrocarbon reservoirs, where CO_2 may be utilized to enhance oil recovery (EOR), offers the prospect of solubility trapping in both the aqueous and hydrocarbon phases. Here, CO_2-EOR may provide a greater a quantity of securely stored CO_2 than a purely non-EOR storage operation.

The objective of this study was to quantify how much solubility trapping takes place within both aqueous and hydrocarbon phases in CO_2-EOR settings, using a simplified reservoir simulation model. The model was based on data from the Pembina Cardium CO_2 Monitoring Pilot (PCCMP) project, set up in west-central Alberta, Canada, as a trial for the study of the injection of CO_2 with combined EOR. The pilot was sited in a mature oil field which had been extensively water-flooded for nearly 50 years.



Notional partitioning and long term security of storage of CO_2 in geological formations (after IPCC Special Report, 2005)

Model development

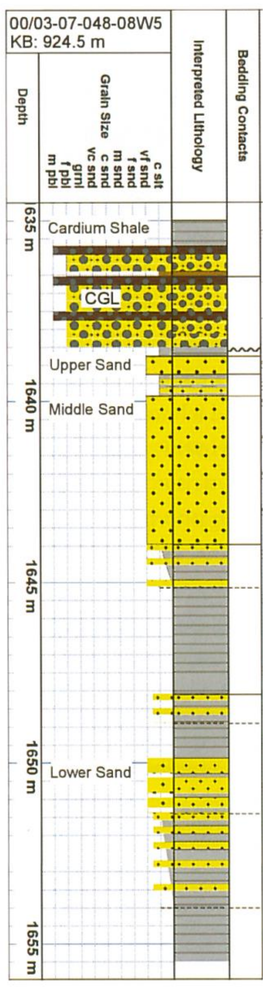
The original water-flooding phase had no definitive well pattern/density, but was nominally an inverted 9-spot on a 40 acre well spacing, although there were also some injectors in line drive pattern. The trial CO_2 injectors were incorporated at the site in two five-spot patterns.

A GEM compositional reservoir simulation model was developed using CMG Builder software. The lithology from one well in the Cardium formation was used to differentiate the various rock types. The model was constructed with a small NE-SW trending dip angle and wells were located at the four corners of the model, with 3 producers at the NW, NE and SE corners and a water injector at the SW corner. The CO_2 injector was located in the centre of the model.

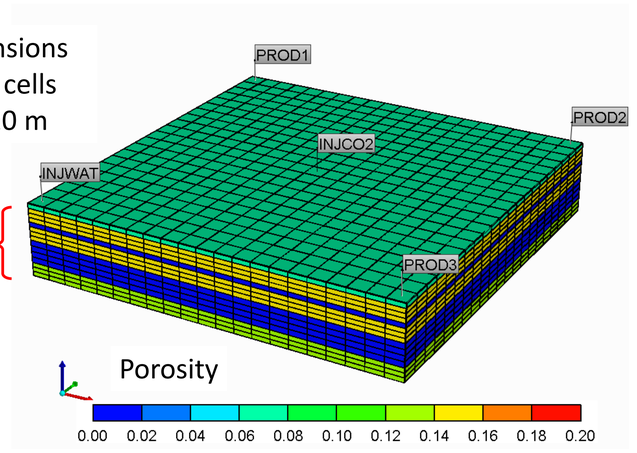
Formation relative permeability data was available from the PCCMP Final Report, however in the absence of suitable data, generic PVT data from a CMG CO_2-EOR WinProp/GEM training course was utilized. This was a lumped 7-component fluid model with a minimum miscibility pressure (MMP) which had been matched to a laboratory determined value of approximately 2510 psi (17.31 MPa) at the Cardium reservoir temperature of 53°C.

The solubility of CO_2 and the other hydrocarbon components in water was calculated using Henry's Law with Harvey's correlation used for CO_2. For the simulations reported here the water salinity was taken to be zero.

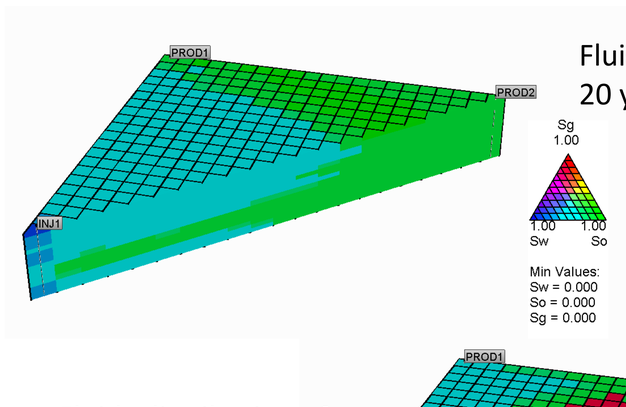
Cardium Formation Lithology



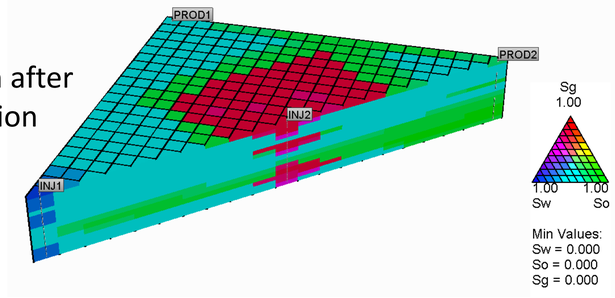
Model dimensions
21 ×21 × 15 cells
DX = DY = 20 m



Fluids distribution after 20 years water-flooding



Fluids distribution after 2 years CO_2 injection

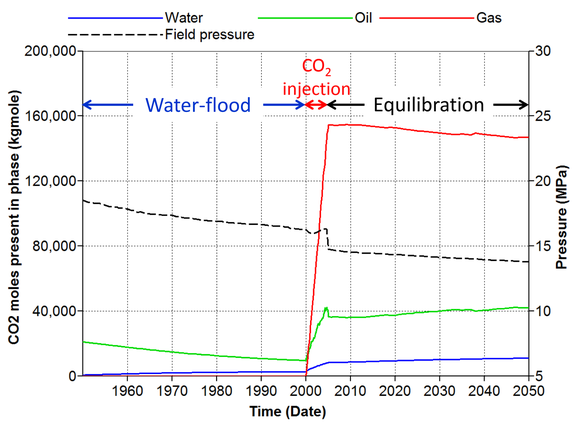


Simulations

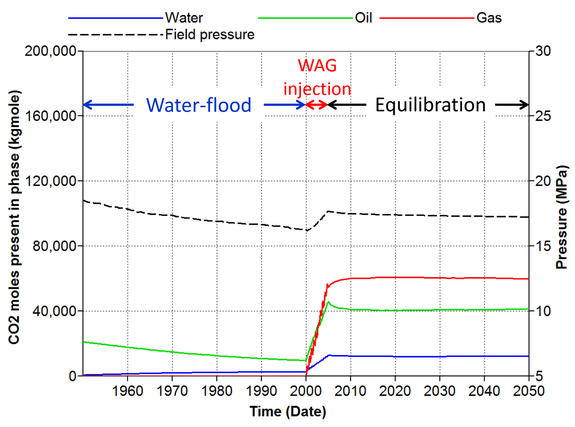
The model was run in four separate configurations:

- Continuous CO_2 injection for 5 years following 50 years water-flood
- Water alternating gas (WAG) injection on a 3 months cycle for 5 years following 50 years water-flood
- As a depleted oil field for 5 years following 50 years water-flood
- As an aquifer with continuous CO_2 injection for 5 years.

Continuous gas injection (CGI)



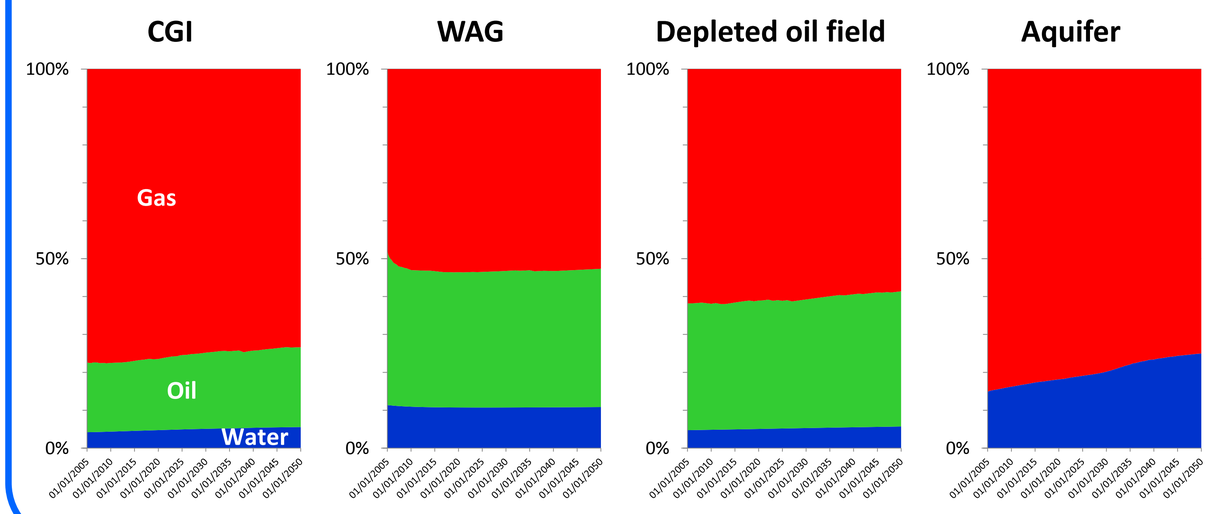
Water alternating gas (WAG)



Results

The simulation results indicate that for this approximative model of the PCCMP pilot, after injection ceases, the CO_2 has a greater affinity to dissolve in the oil rather than the water. Under the reservoir and fluid conditions in this system, when oil is present, more CO_2 dissolves in the oil than dissolves in the water. The CO_2 also dissolves more quickly in the oil than in the water.

The fraction of CO_2 that dissolves in the oil is greatest for WAG injection, despite the fact that only half the time of the injection period is spent injecting CO_2 and the other half of the time injecting water. Cases with oil present equilibrate more quickly than in the case with no oil present i.e. aquifer. In the latter case there is still ongoing dissolution of CO_2 in the water taking place 50 years after injection started. The presence of oil in the subsurface is therefore beneficial to storage security in this system.



References

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2. Penn West Energy Trust, Pembina Cardium 'A' Lease - CO_2 Pilot Project: Annual Reports, 2005 – 2007.
3. Computer Modelling Group, CO_2 EOR Modelling Using GEM - Course Notes, 2014.

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