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Technology Collaboration Programme by iea

Gas inection in a low-permeable chalk reservoir: Comparison between hydrocarbon gas, flue gas, and CO_2

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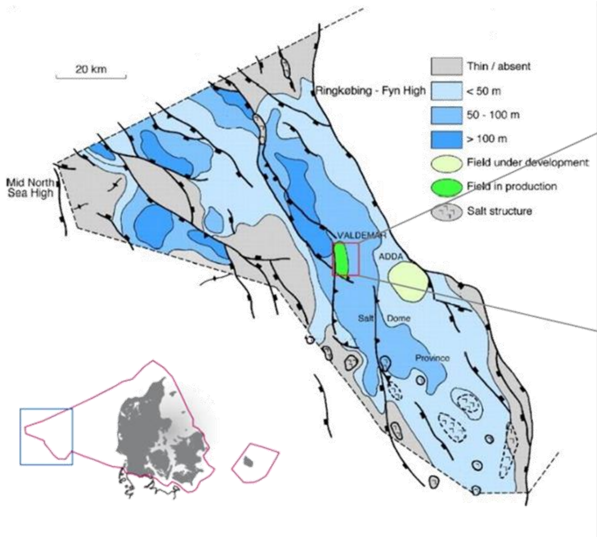
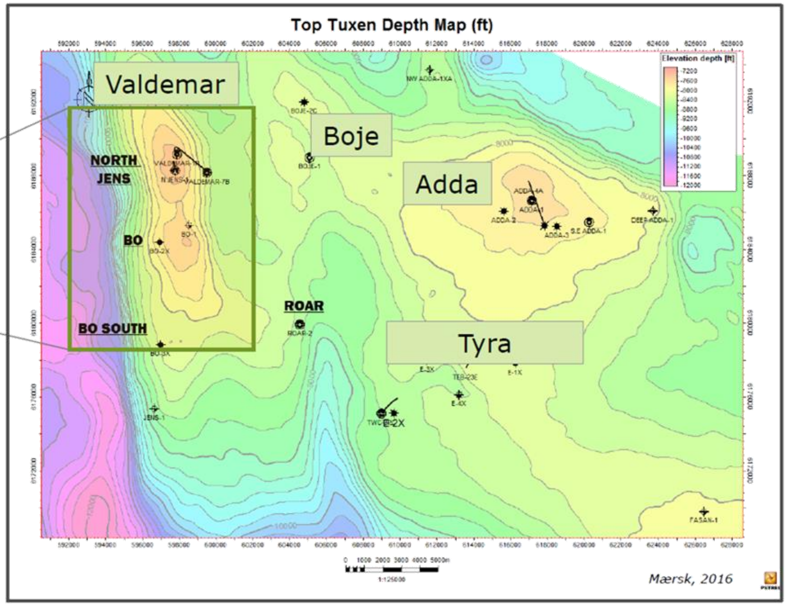
eor Enhanced Oil Recovery

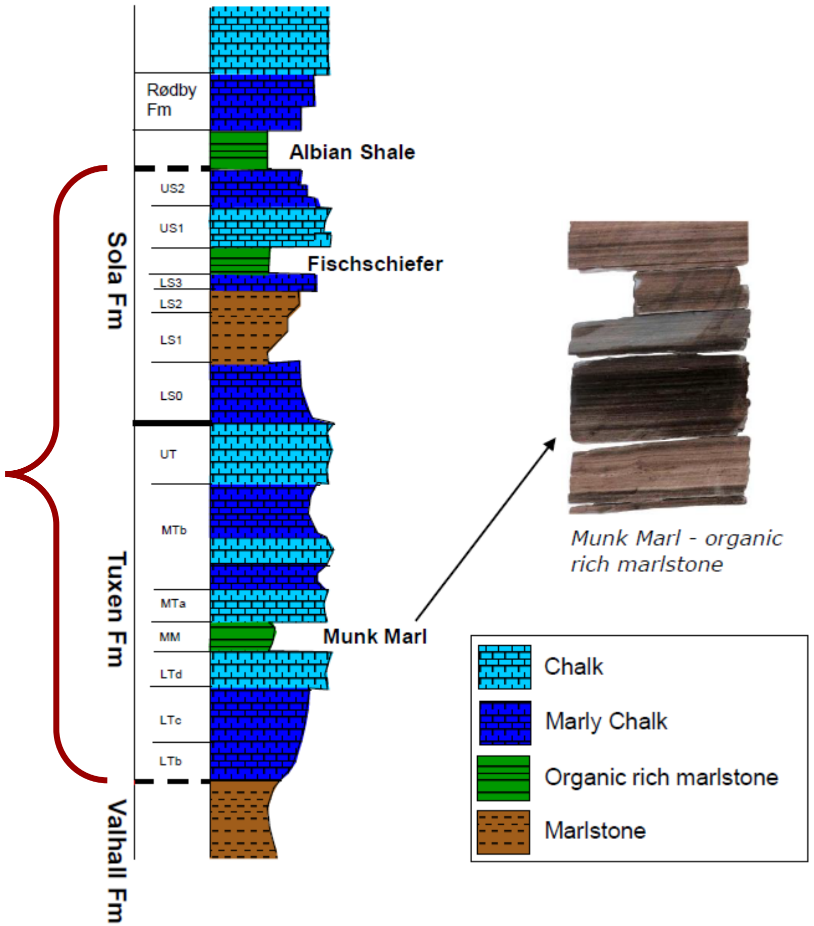
Introduction to Valdemar Field

- Lower Cretaceous reservoirs
- Location: Central part of the Danish Central Graben, 20 km NW of the Tyra Field
- Production: Natural depletion from 1993
- Depth ~ 2200 m
- Thickness: 50 - 150 m
- Porosity: 15 - 35%
- Permeability < 1 mD



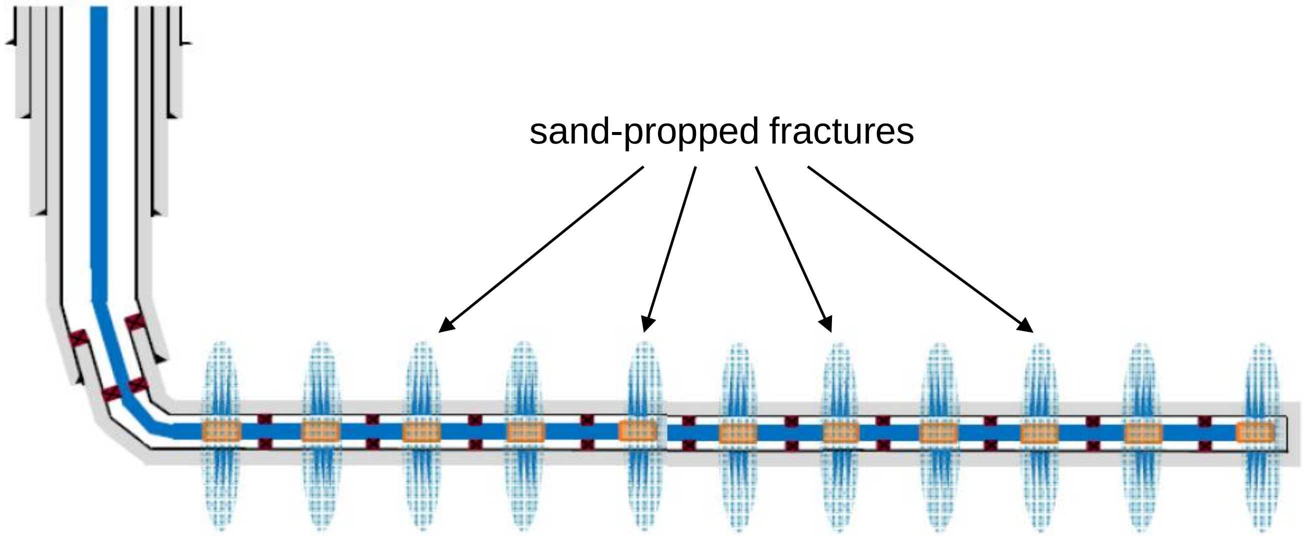
Thickness Lower Cretaceous Tuxen/Sola Formation; Jakobsen et. Al. 2004

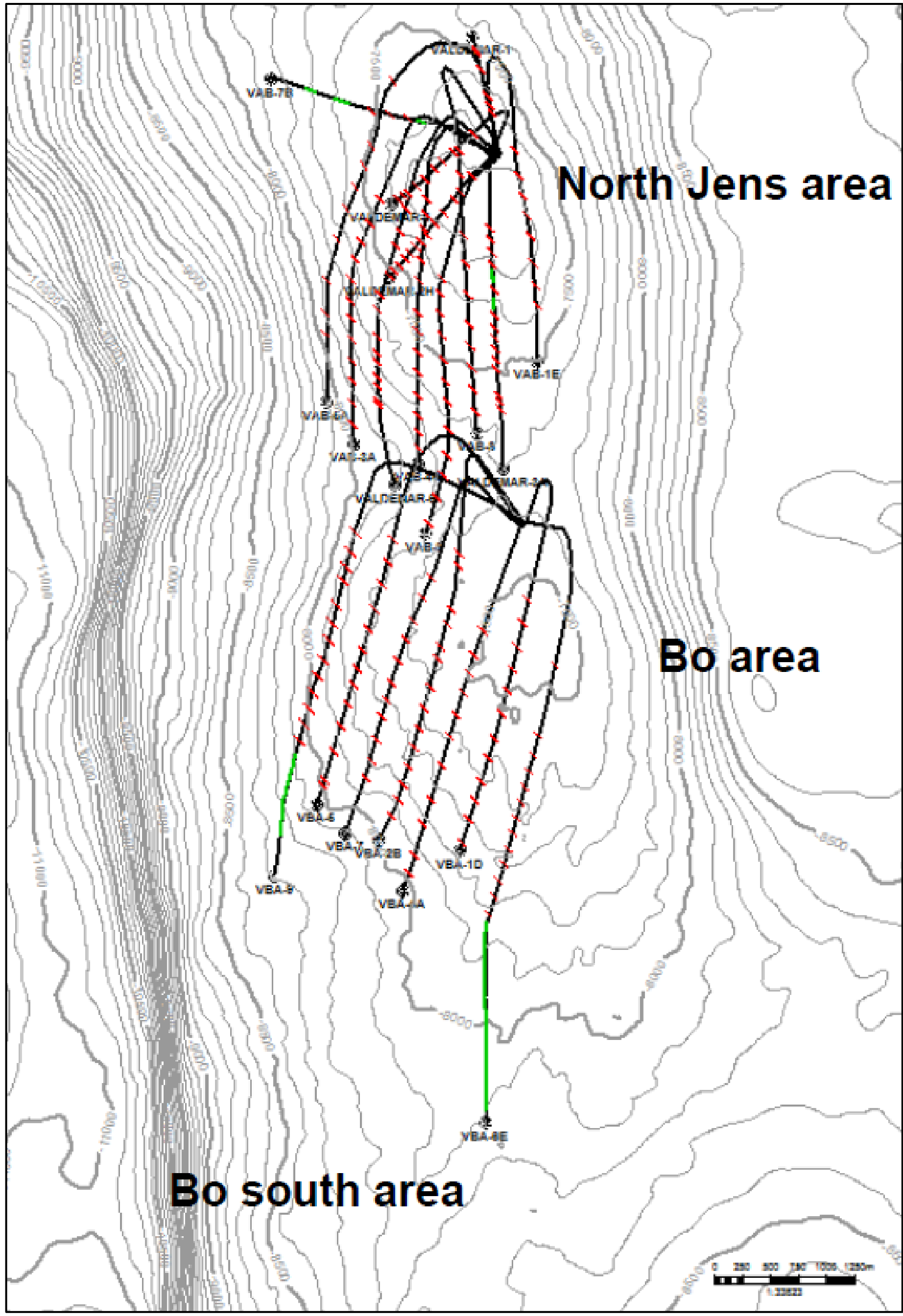




Valdemar Wells

- 16 active horizontal wells in total:
  - North Jens: 9 producers and 3 abandoned wells
  - Bo: 7 producers
  - Bo south: undeveloped
- Typically 3000 m in lateral
- Completed with sand-propped fractures (~ 200 m spacing)





Objectives

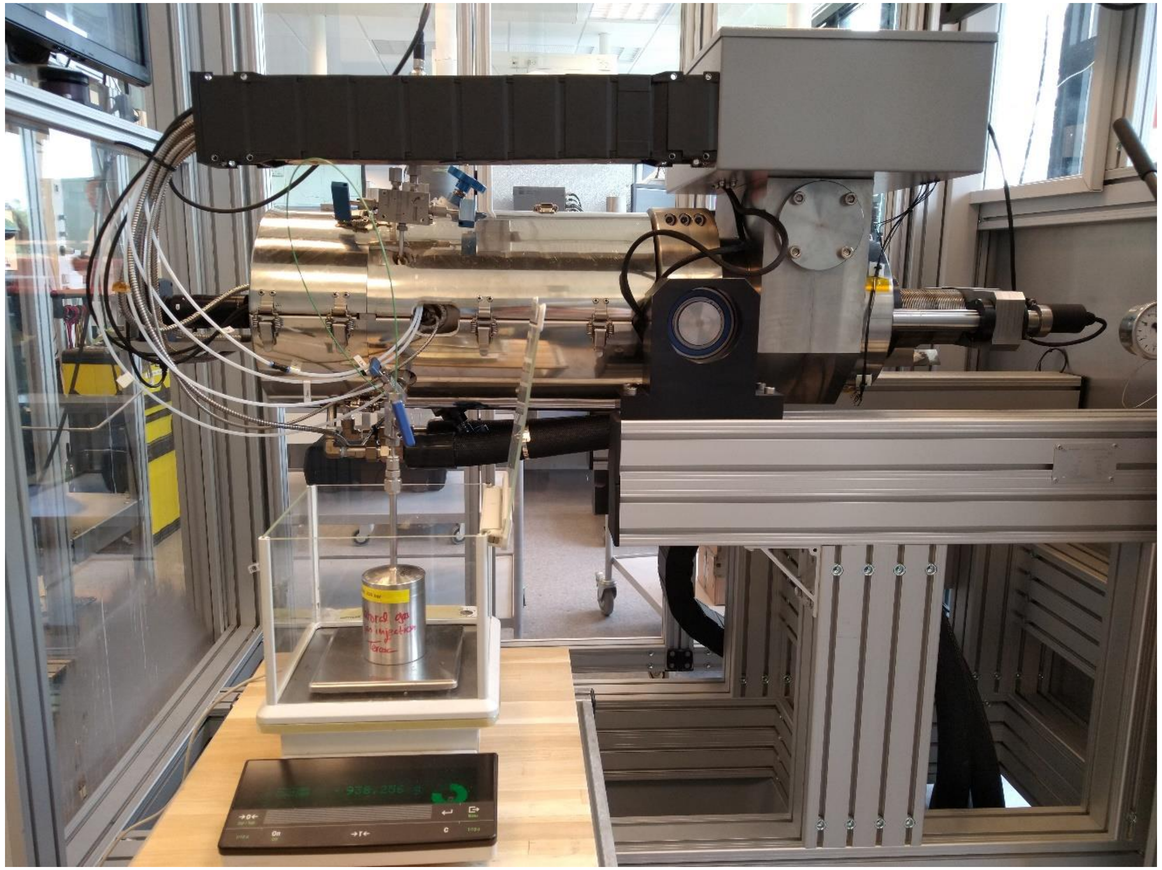
- Evaluate gas injection in the Lower Cretaceous reservoirs
- Although hydrocarbon gas is the main focus, a comparison with other gases (flue gas and CO_2) is made as part of the research project.
- For CO_2 and flue gas, the additional benefit of sequestering CO_2 can be investigated.

Scope of study

- Relevant laboratory measurements: PVT study and flooding tests
- Development of the fluid model and history matching of the flooding tests
- Simulation of a conceptual model for Lower Cretaceous reservoirs
  - Building a conceptual model for LCr reservoirs based on the Valdemar field
  - History matching the pressure and production history of the wells in the model
  - Evaluating the efficiency of different injection gases in enhancing the oil recovery from the reservoir
  - Investigating the CO_2 storage efficiency in scenarios where the injected gas contains CO_2

PVT study

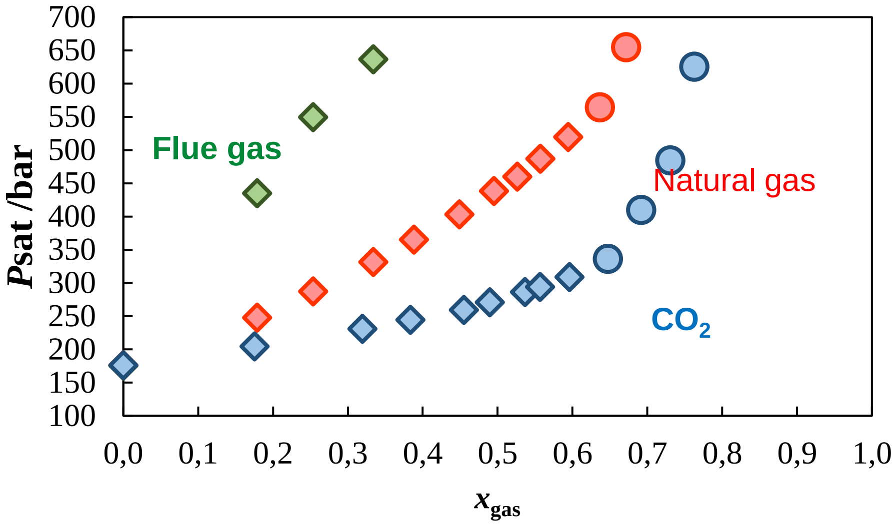
- Routine PVT + Swelling tests with hydrocarbon gas, flue gas, and CO_2

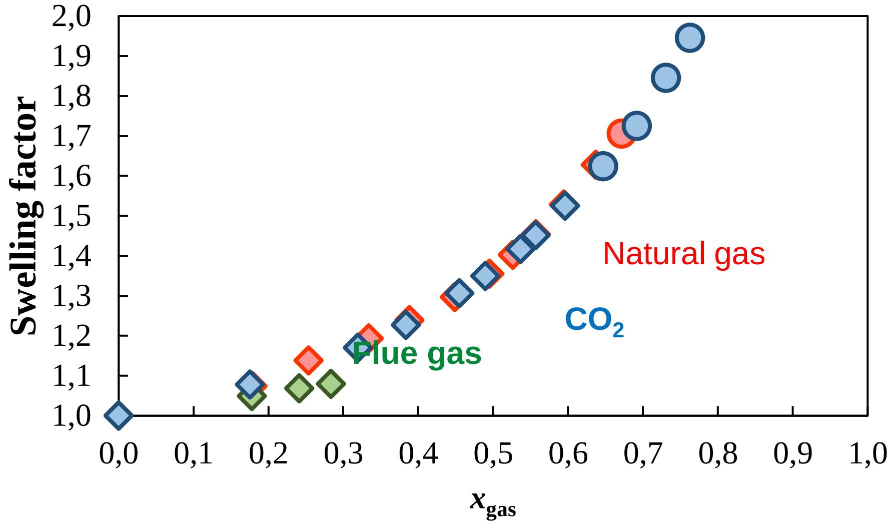


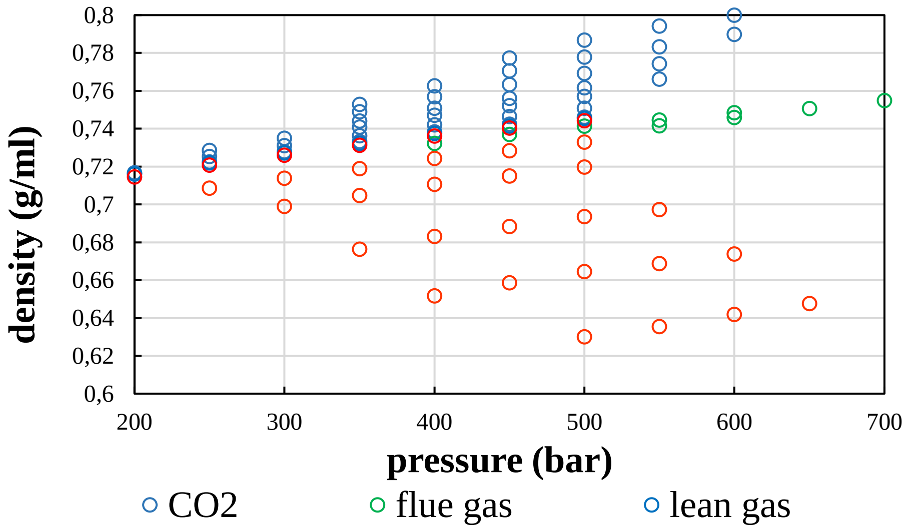
Component	Oil	Lean gas	Flue gas	CO_2
N_2	0.00281	0.00311	0.87	-
CO_2	0.00466	0.0097	0.13	1
C_1	0.38826	0.89032	-	-
C_2C_3	0.09744	0.0835	-	-
C_4	0.03910	0.01047	-	-
C_5	0.02761	0.0024	-	-
C_6	0.02962	0.0005	-	-
C_7C_{12}	0.20751	-	-	-
$C_{13}C_{18}$	0.09073	-	-	-
$C_{19}C_{29}$	0.06452	-	-	-
$C_{30}C_{80}$	0.04773	-	-	-

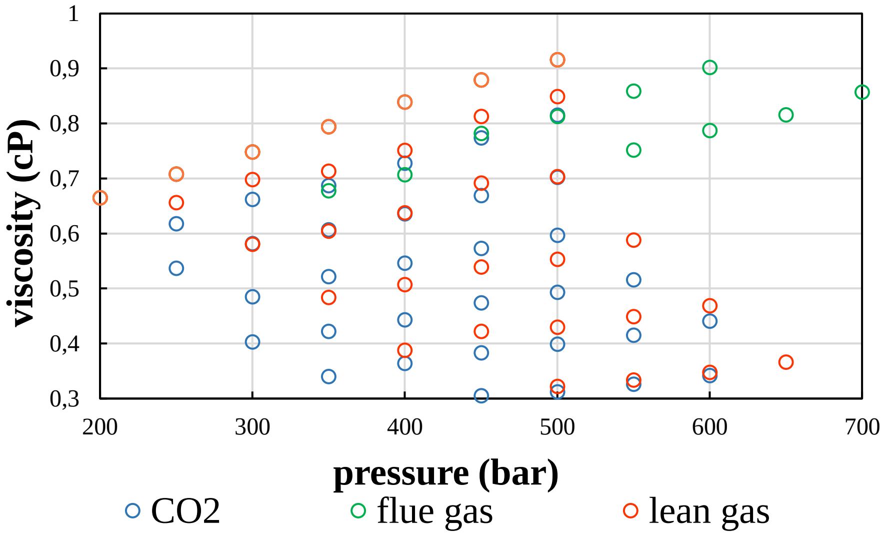
PVT study

- P_b= 181 bar, GOR= 111 sm^3/sm^3









x_{gas} range in density/viscosity

lean gas 0-0.5

CO_2 0-0.6

flue gas 0-0.2

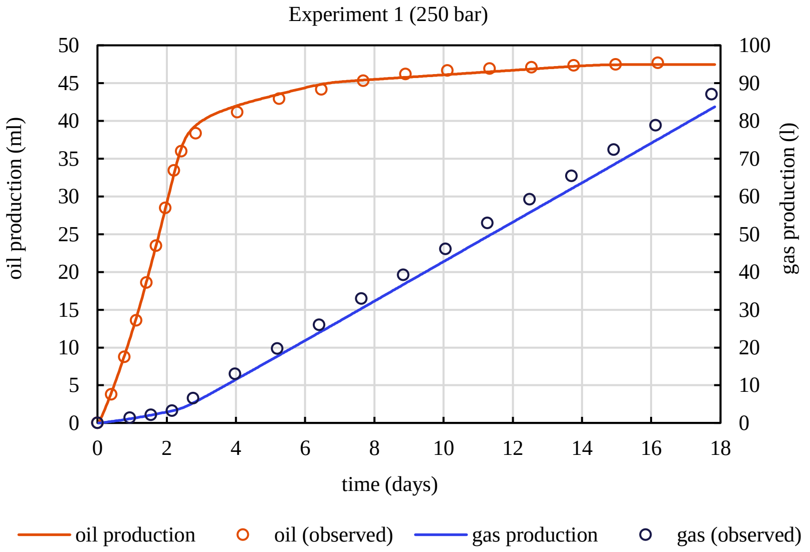
Flooding tests

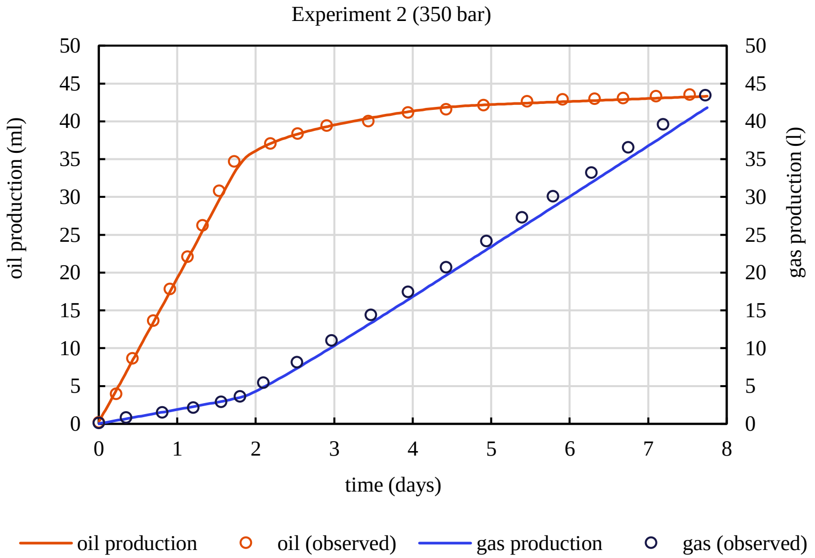
- Composite core flooding using natural gas at 250 and 350 bar

Parameter	Unit	Experiment 1	Experiment 2
Number of core plugs	-	5	6
Average porosity	%	34.05	34.33
Total pore volume	ml	137.88	100.57
Average Klinkenberg permeability	mD	0.432	0.287
Average initial water saturation	%	20.7	24.6
Pressure	bara	250	350
Temperature	$^\circ$ C	85	85
Miscibility conditions	-	Immiscible	Near-miscible
Separator pressure	bara	5.3	5.3
Separator temperature	$^\circ$ C	30	30
Total time of gas injection	days	26	14
Gas injection rate	rml/hr	1.03	1.03
Total oil production	ml	47.5	43.0
Recovery factor	%OOIP	**58.1** @ 2.81 PV_{inj}	**74.8** @ 1.95 PV_{inj}

History matching of the flooding tests

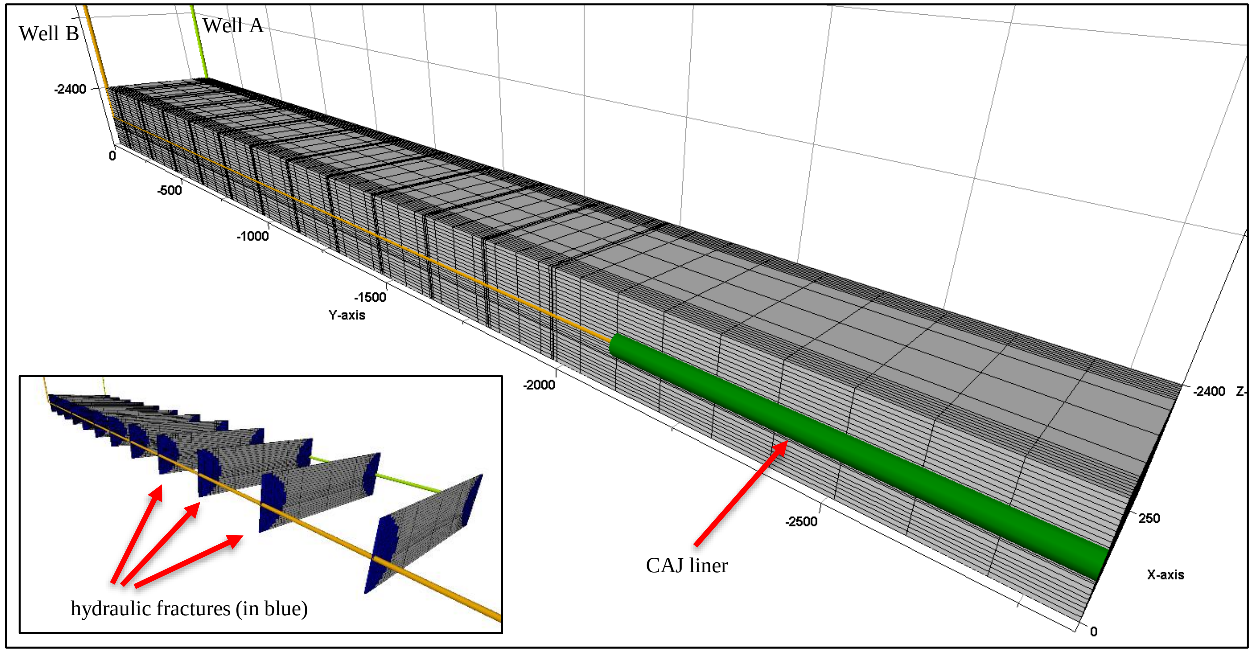
- Tuning of the absolute permeability within its uncertainty range to match the pressure difference
- Modify the rel perm curves in areas with no experimental measured data--measured points in SCAL kept
- Non-vaporizing oil saturation defined using the SOR keyword to avoid excessive vaporization of oil into gas
- Use of the IFT dependent rel perm at near-miscible conditions.



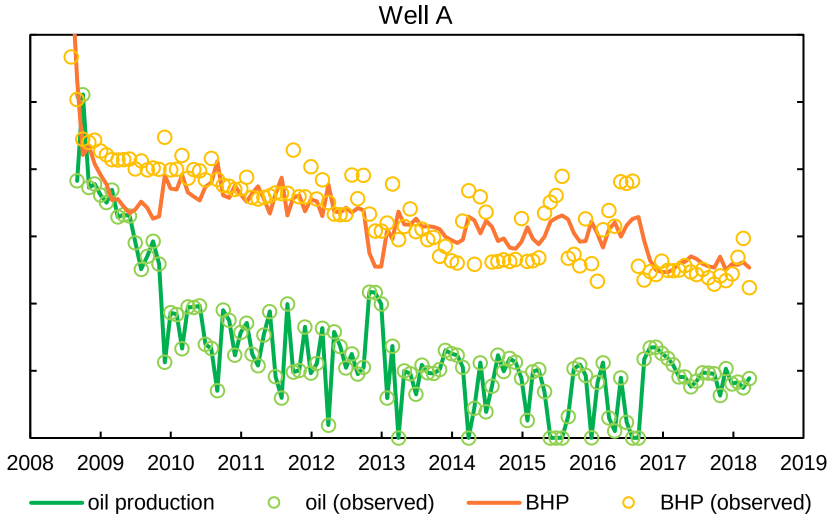


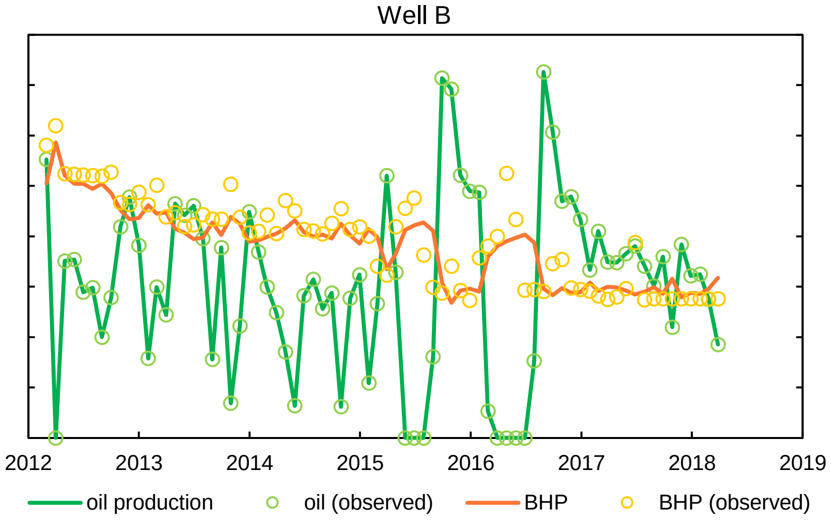
Conceptual Model Properties

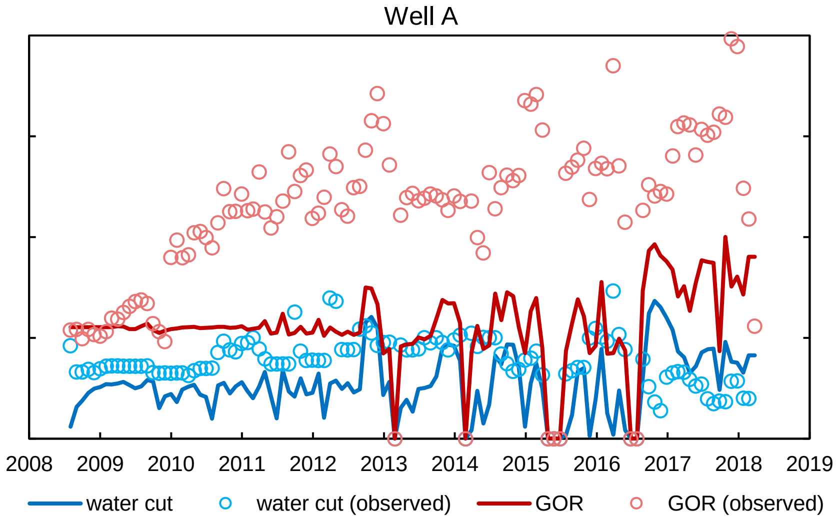
- The area between two horizontal wells with a distance of 300 m
- Reservoir is assumed to be symmetrical around the wellbores
- Model dimensions: 20×91×27
- Finer gridding in the areas closer to the fractures and coarser in more distant zones
- Wells defined completely horizontally in layer 13
- 12 completion zones with hydraulic fractures
- Length of each completion zone: 6 ft
- A long interval completed with liner in well B
- Hydraulic fractures spacing: 170 m
- Fracture radius: 100 to 150 ft
- Horizontally homogeneous (except for fracs) with constant average properties for different layers
- P_i = 361.5 bara & T_i = 87 °C @ 2400 m

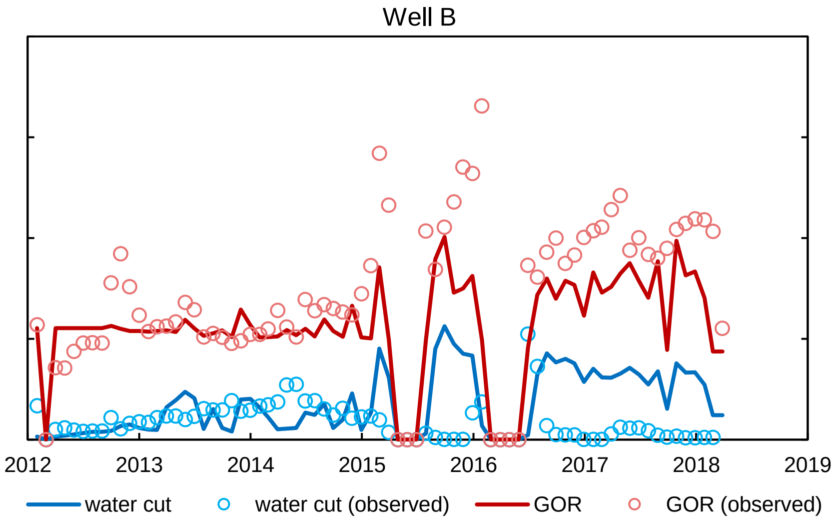


Modeling of the depletion period



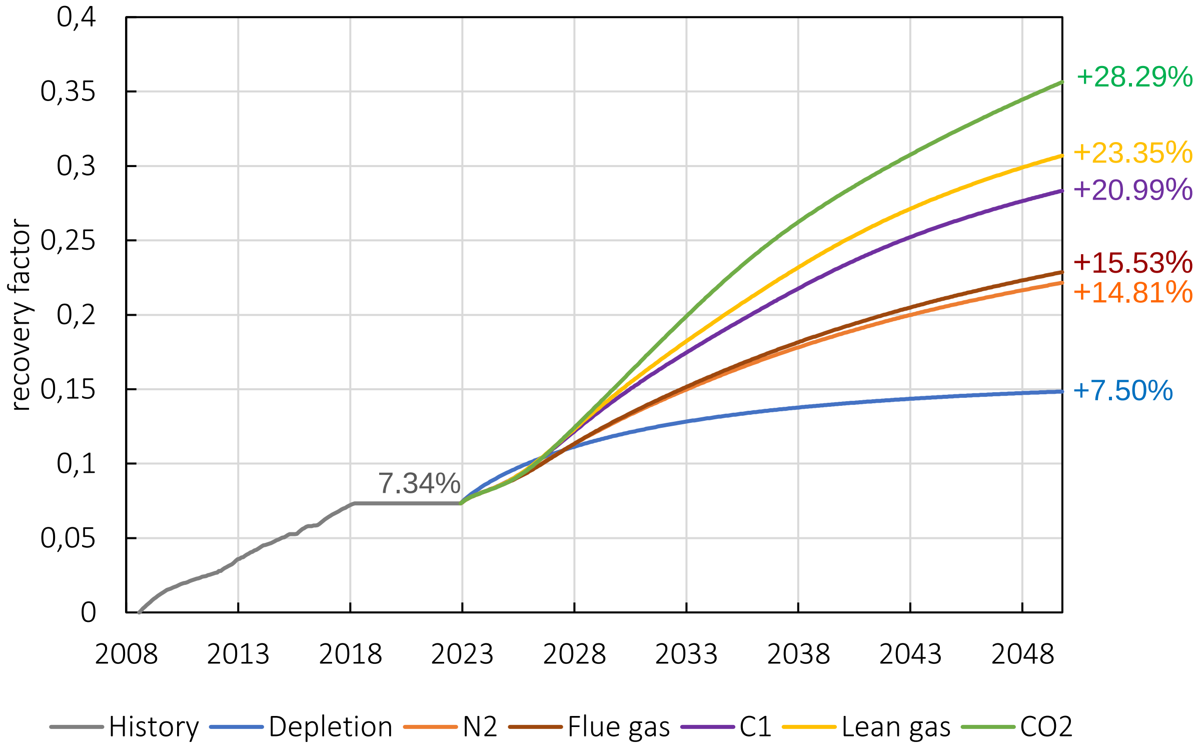






Prediction Scenarios

- Defined scenarios:
  - Natural depletion: both wells produce until 2050
  - Gas injection: Different types of gases are injected in well A while well B remains a producer:
    - Lean gas (~ 90% methane)
    - Flue gas (87% N_2 + 13% CO_2)
    - Pure CO_2
    - Pure methane
    - Pure nitrogen
- Prediction constraints:
  - Prediction period: **2023 – 2050**
  - Minimum BHP of production well(s): **90 bara**
  - Maximum gas injection rate: **12.5 MMSCF/day**
  - Maximum BHP of injection well: **361.5 bara**



Advantages of CO_2

Much higher density at reservoir conditions

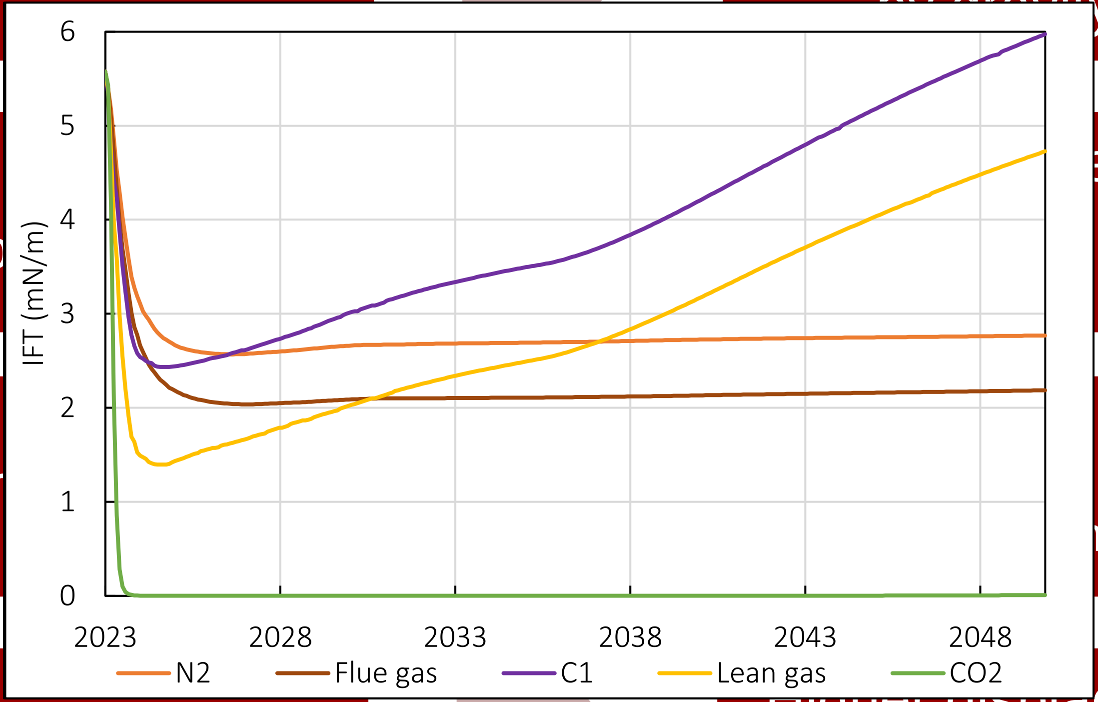
Higher displacement efficiency and lower oil bypassing caused by gravity segregation

Higher viscosity conditio

e mobility ratio and effects leading to breakthrough

More compr

of CO_2 can be stored more attractive from nental perspective

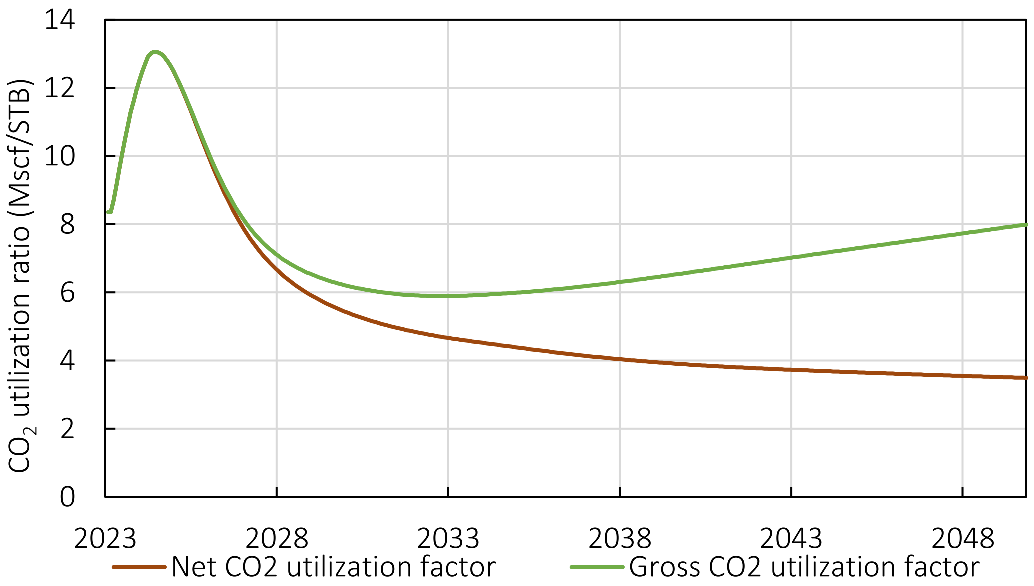


Much lower MMP with oil

Higher displacement efficiency and lower residual oil saturation due to low capillary forces

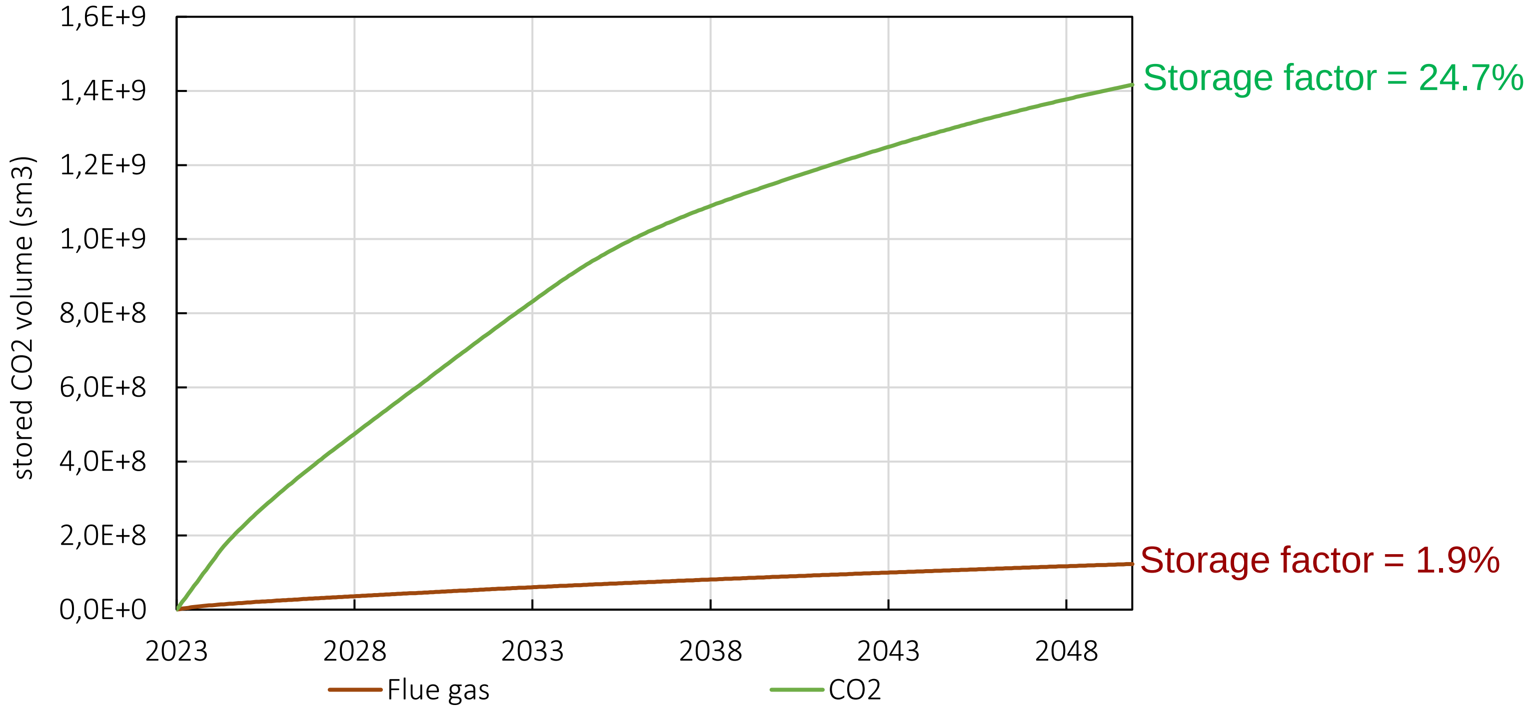
CO_2 Utilization Ratio

- An important economic indicator for evaluating the cost-effectiveness of the CO_2 injection implementation for enhanced oil recovery.
- Refers to **the volume of CO_2 that needs to be injected in order to produce one barrel of oil**
  - Gross utilization ratio includes the total injected CO_2
  - Net utilization ratio only considers purchased CO_2 (total injected CO_2 – produced/recycled CO_2)
- Minimizing the CO_2 utilization ratio is favorable.
- Typical values for net utilization factor are in the range of 4 to 15 Mscf/STB



CO_2 Storage Efficiency

- TRACER option of the Eclipse was used.
- **CO_2 retention factor:** the ratio of the amount of CO_2 stored to the total amount of injected CO_2 (between 43% and 44% for both cases).
- **storage efficiency or storage factor:** the ratio of the volume of CO_2 stored to the total pore volume of the reservoir



Conclusions

- Gas injection is an efficient EOR method in tight chalk Lower Cretatceous reservoirs.
- CO_2 has the highest (28.3%) and N_2 has the lowest (14.8%) incremental recovery among the injected gases in this study.
- Incremental recovery: **CO_2 ~ 2 × N_2 ~ 4 × Natural depletion**
- The main advantage of CO_2 is its lower MMP with oil. In addition, its higher viscosity, density, and compressibility are also beneficial for CO_2 EOR.
- The net CO_2 utilization ratio reaches a minimum of 3.5 Mscf/STB at the end of the injection period in this study, showing the efficiency of CO_2 EOR from the economic viewpoint.
- In this study, ~44% of the injected CO_2 will be retained in the reservoir.

¡THANKS!

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