MOBILITY CONTROL OF CO_2 DURING AQUIFER STORAGE

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and Torleif Holt

Outline

- Introduction
- Surfactant partitioning between water and CO_2
- Flow properties of foam
- Surfactant adsorption
- Simulation
- Interfaces
- Summary

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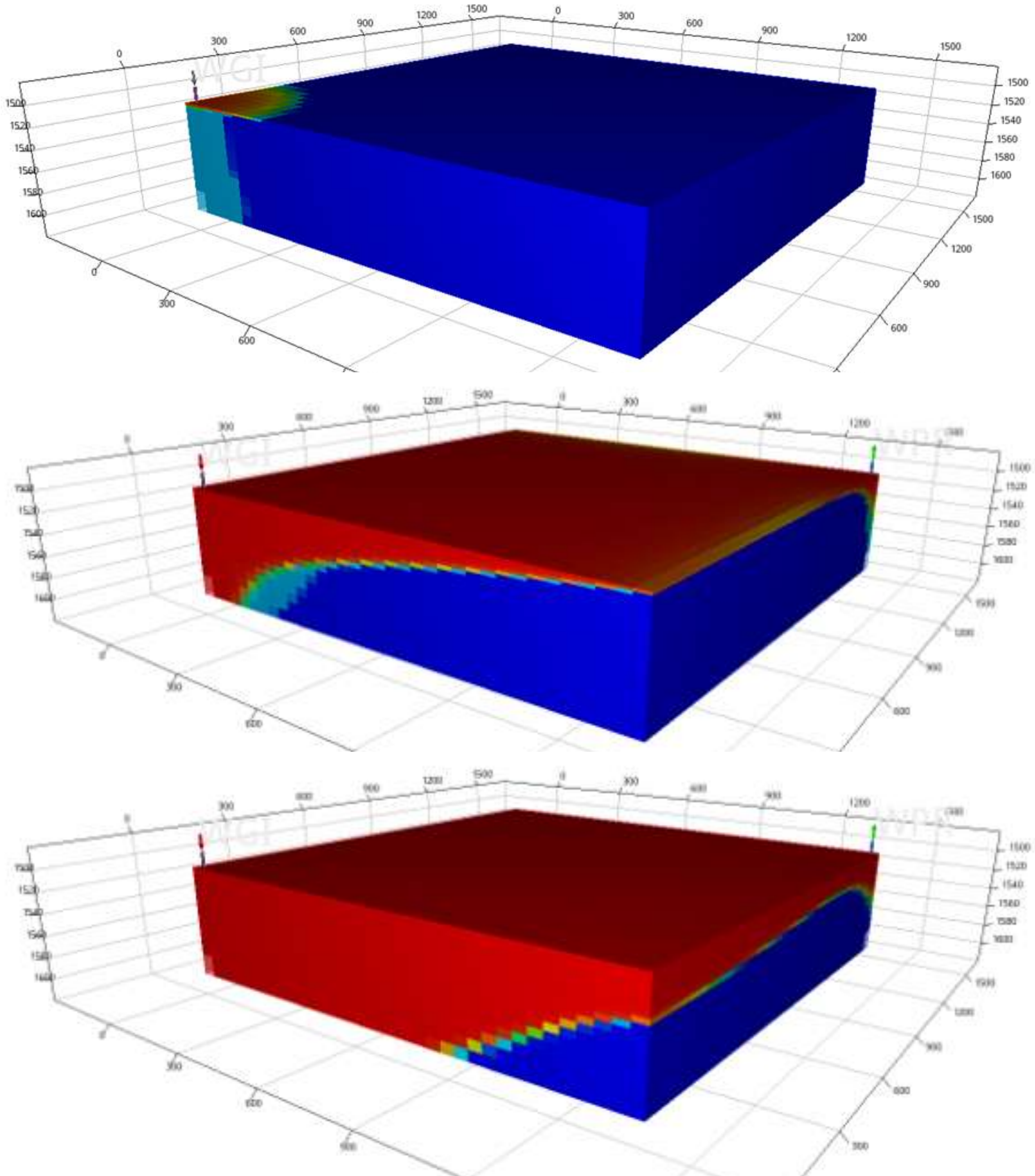
Introduction

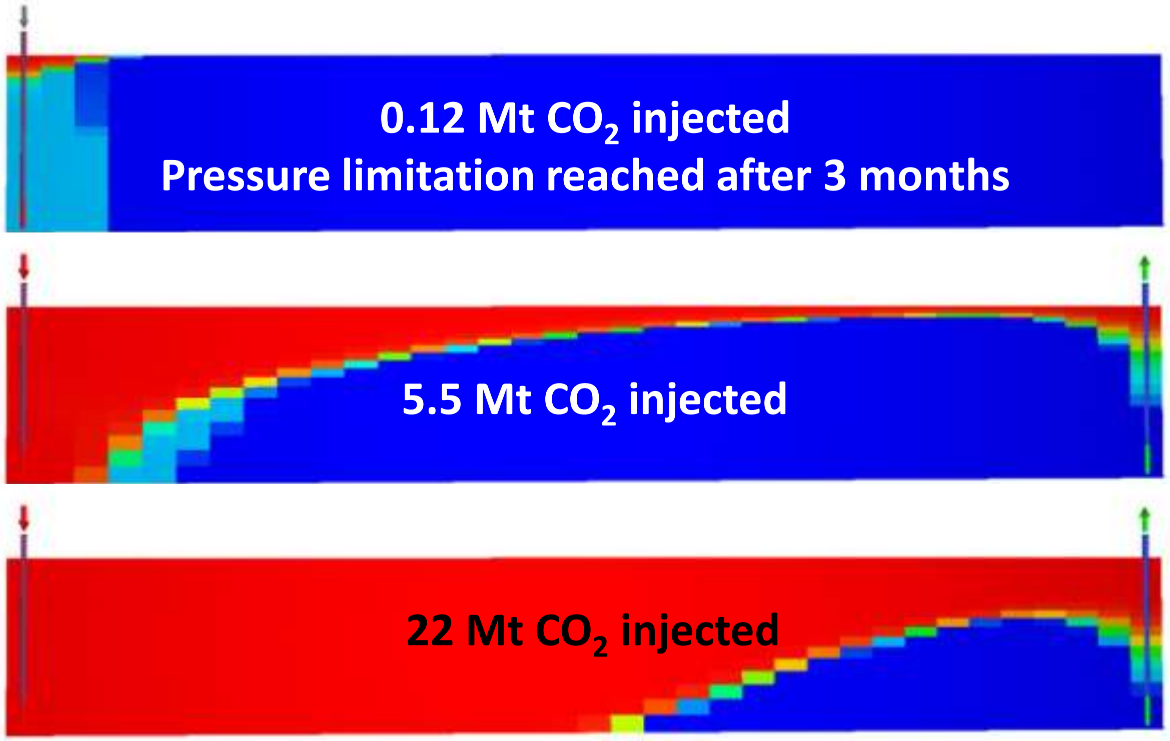
- Why mobility control?



Introduction

How can CO_2 mobility be reduced?

- Foam
  - Water soluble surfactants
  - CO_2 soluble surfactants
- Direct CO_2 thickeners
- Nanoparticles
  - Foam
  - Thickeners



Foam simulator development

A simulator is needed for field scale prediction

- A foam simulator must include the following features
  - Adsorption/desorption
  - Surfactant partitioning
  - Foam flow behaviour
  - Foam strength at variable surfactant concentrations

- Simulator
  - Eclipse
    - Do not include all needed features
  - MRST based model
    - Development ongoing

Laboratory experiments

- Surfactant adsorption
- Surfactant partitioning
- Foam flow behaviour
- Interface rheology

→

- Understanding foam behaviour
- Evaluate feasibility of using CO_2-soluble surfactants
- Rank surfactants
- Simulator input

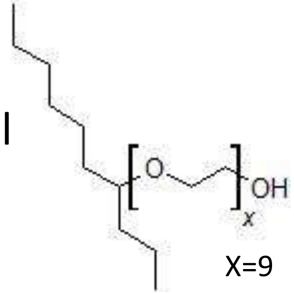
Foam stabilizers (surfactants)

- Alkyl ethoxylates

Brij L23

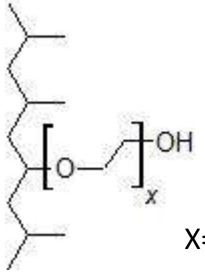
X=23

Tergitol
15-S-9



X=9

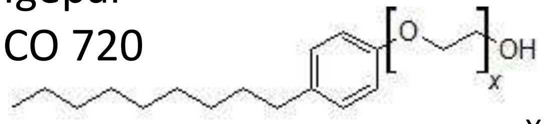
Tergitol
TMN 10



X=10

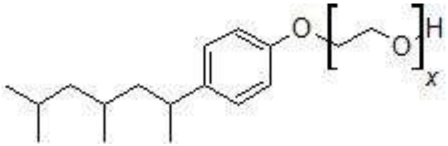
- Alkylphenol ethoxylates

Igepal
CO 720



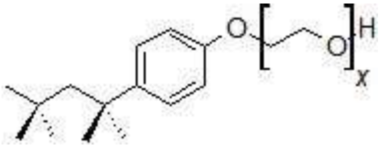
X=12.5

Tergitol
NP 10



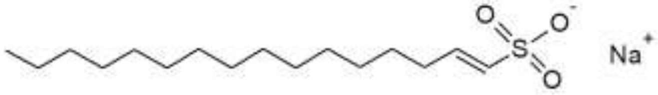
X=12.5

Igepal
CA 720



X=10

- Reference surfactant



Alpha Olefin Sulfonate (AOS)

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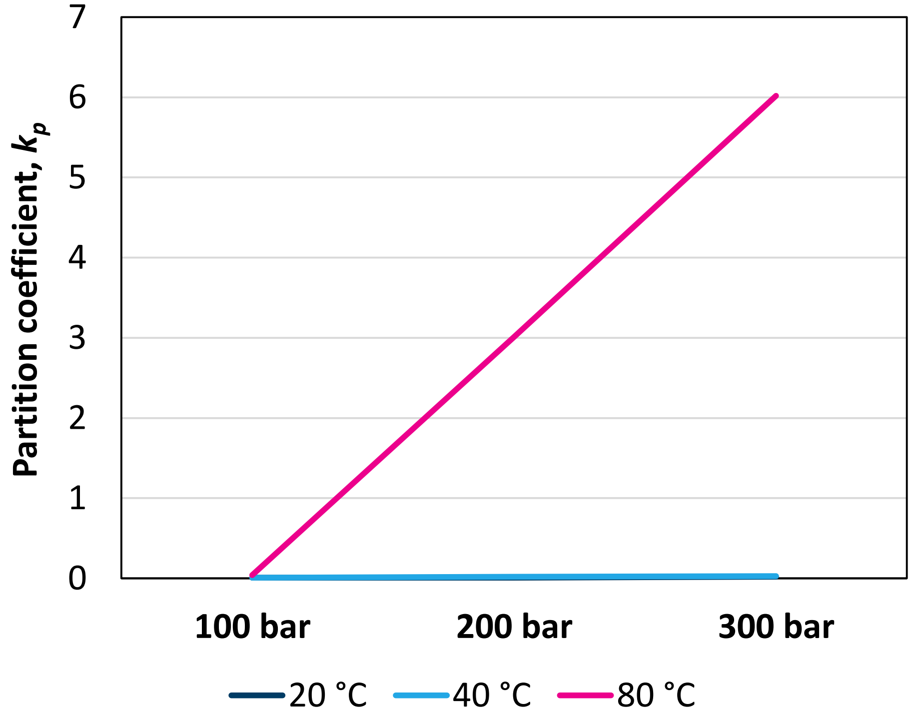
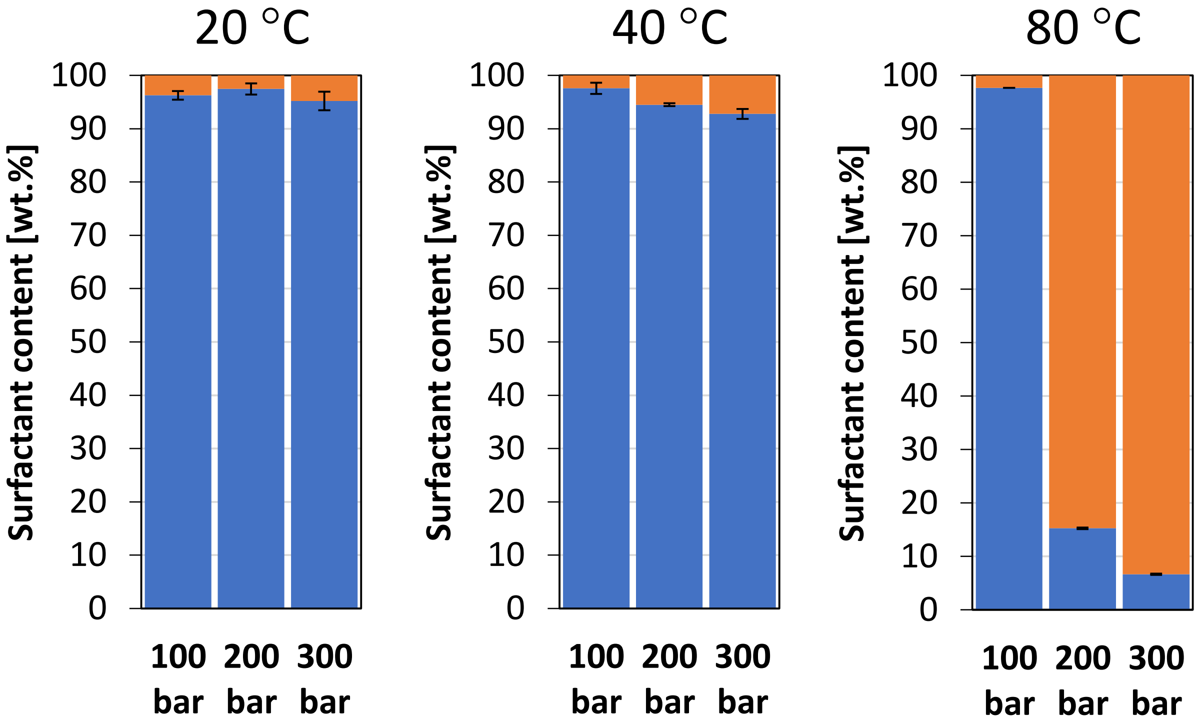
Partitioning, k_p

Brij L23

$$k_p = \frac{\dfrac{m_{s,CO_2}}{m_{s,CO_2} + m_{CO_2}}}{\dfrac{m_{s,H_2O}}{m_{s,H_2O} + m_{H_2O}}}$$





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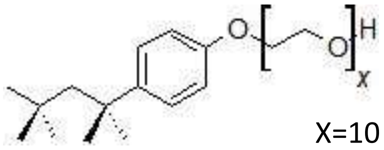
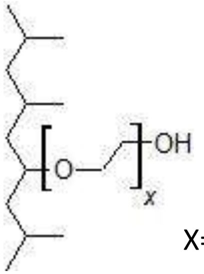
Partitioning, k_p

X=23

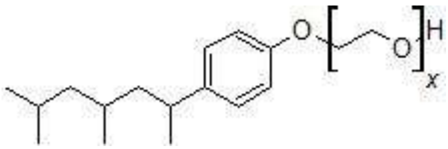


X=10

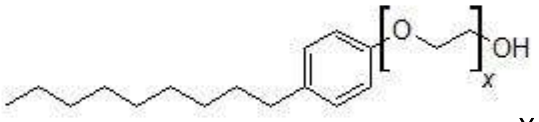


X=10

Brij L23 → Tergitol NP 10 → Igepal CA 720 → Igepal CO 720 → Tergitol TMN 10 → Tergitol 15-S-9



X=12.5



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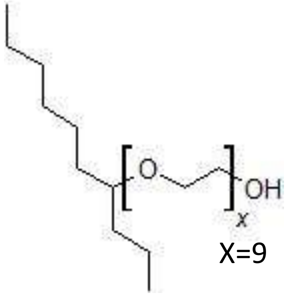
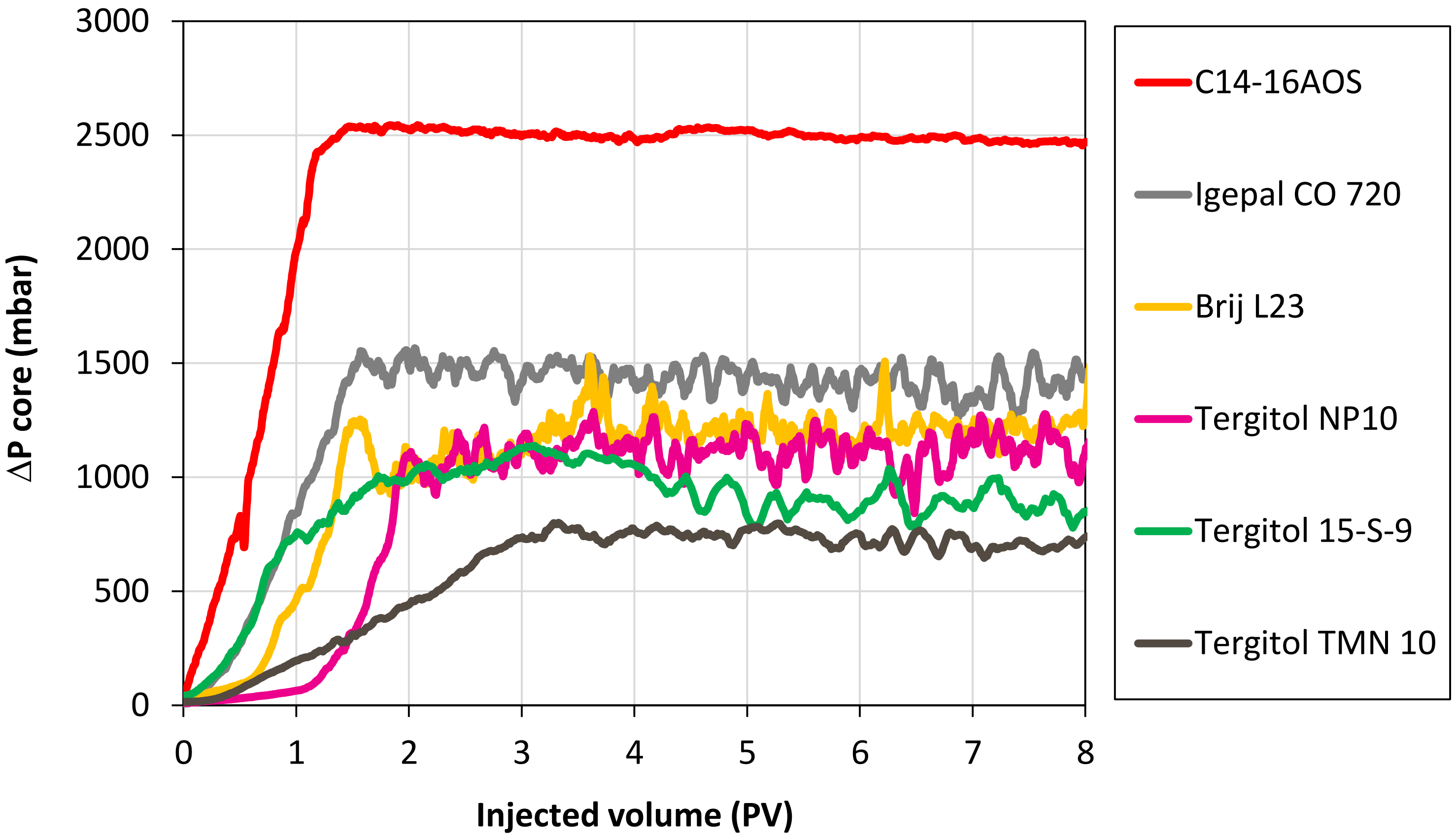


X=9

Steady state coreflooding

- Purpose: determination of relative permeabilities
  - 16 injections for each surfactant
  - Reference AOS
  - Sandstone (20 cm, 2.7 Da)
  - Darcy rate in figure: 0.9 m/d
  - Foam quality in figure: 60 %
  - Pressure: 200 bar
  - Temperature:
    - 80 °C (AOS)
    - 40 °C (non-ionic)



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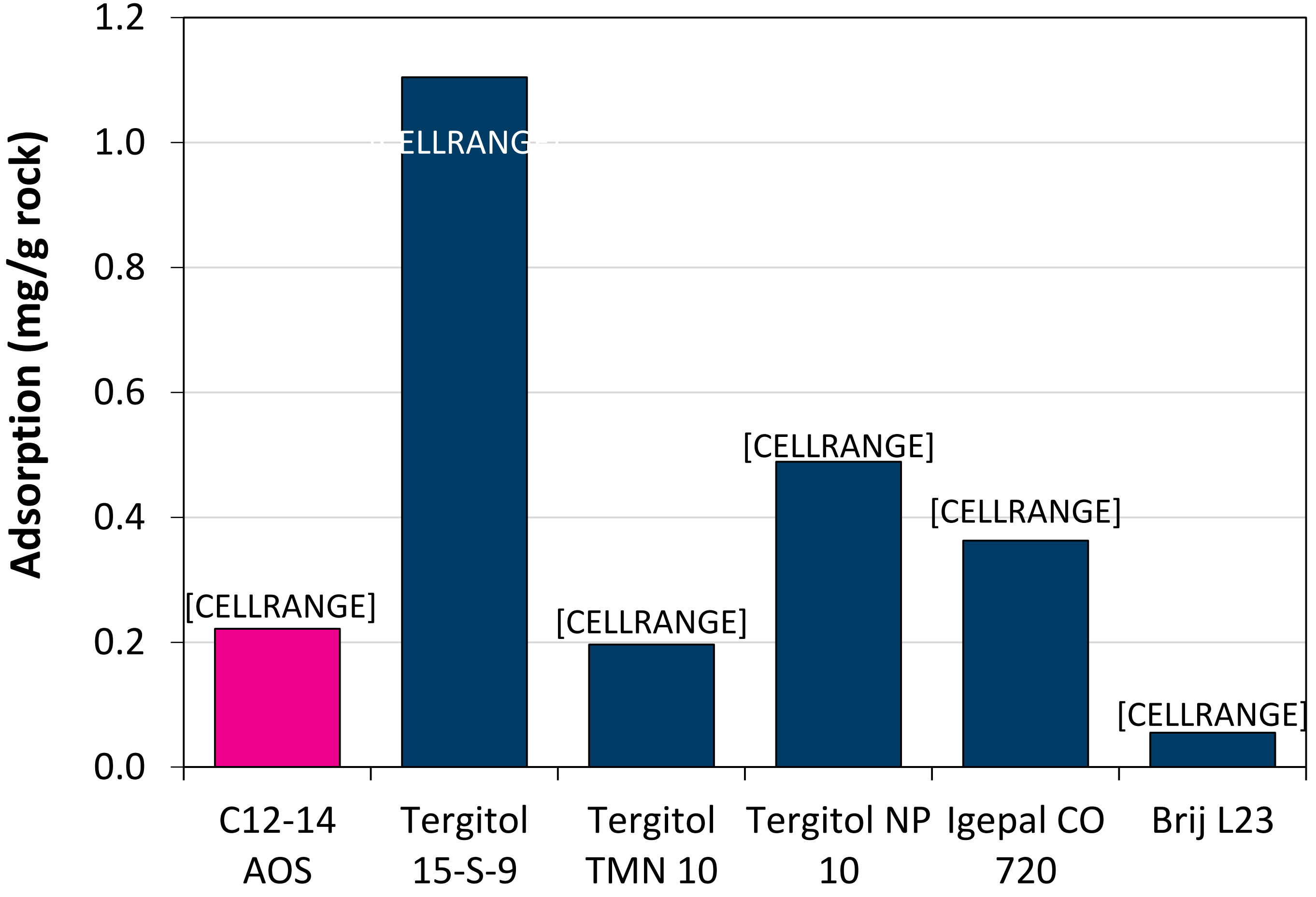
Surfactant adsorption in Bentheimer sandstone



0.5 wt.% concentration in synthetic sea water

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Unsteady state coreflooding – Long core

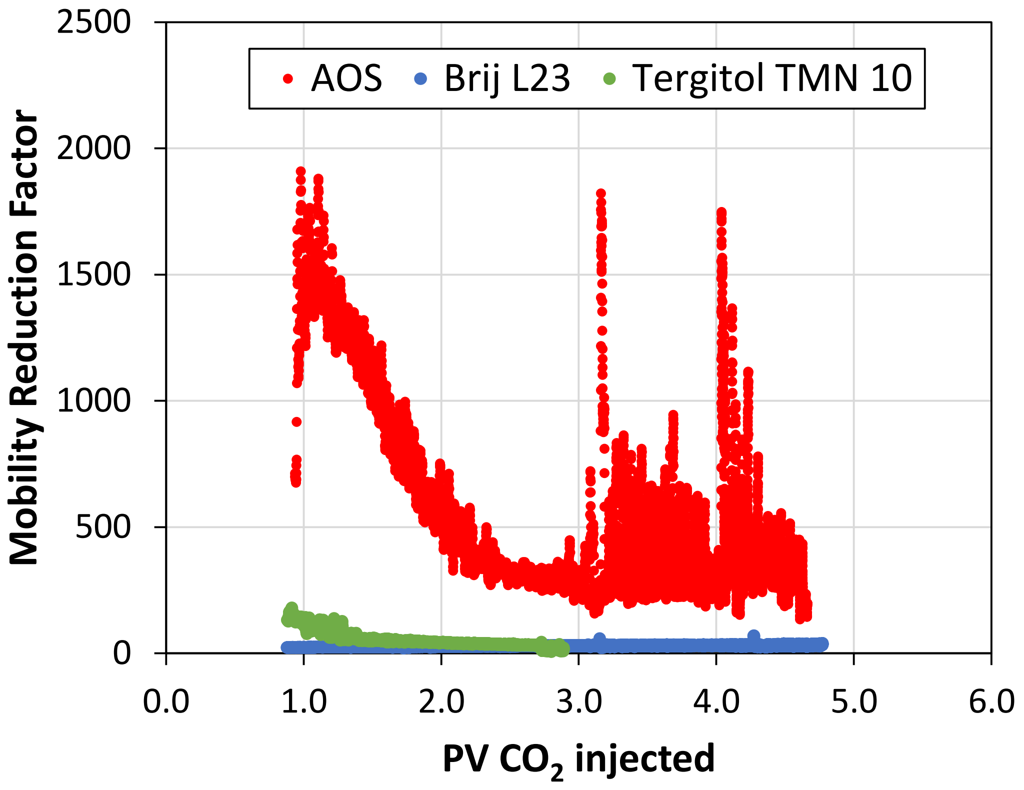
Purpose

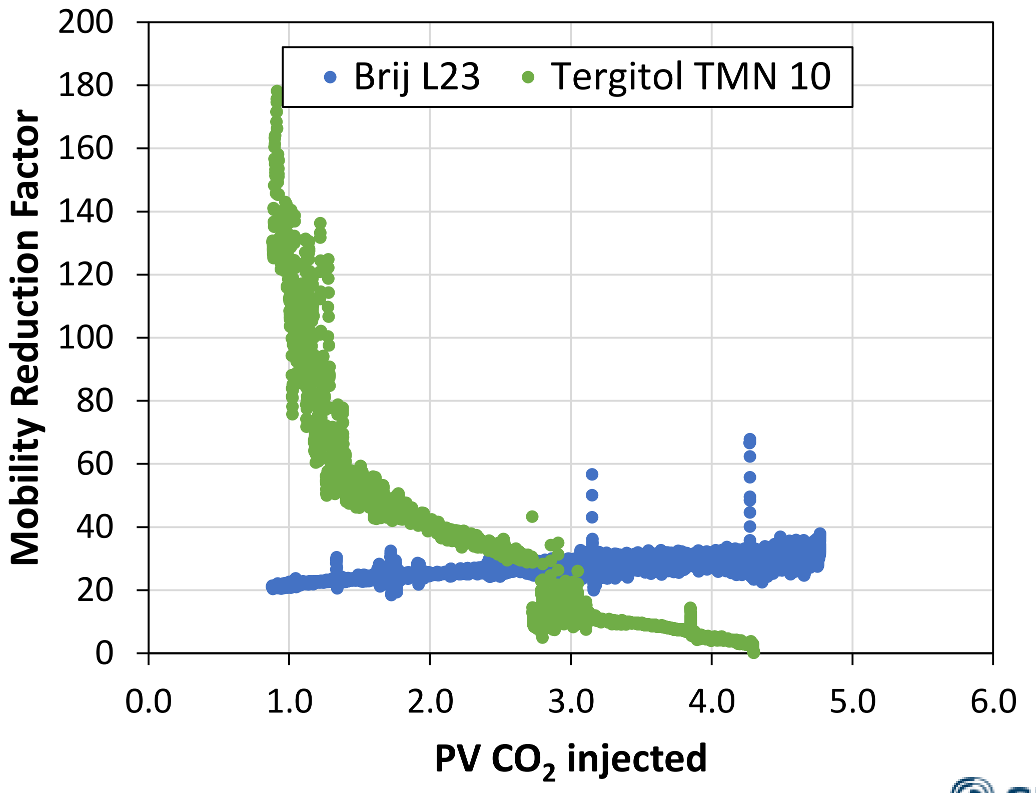
- study foam formation and strength
- provide data for simulator testing
- improve understanding of foam behaviour

- All non-ionic surfactants
- Reference AOS
- Sandstone (115 cm, 2.7 Da)
- Darcy rates: variable
- Pure CO_2 injection
- Pressure: 200 bar
- Temperature:
  - 80 °C (AOS)
  - 40 °C (non-ionic)

Unsteady state coreflooding – Long core

$$Mobility\ Reduction\ Factor = \frac{\Delta P_{foam}}{\Delta P_{no\ foam}}$$



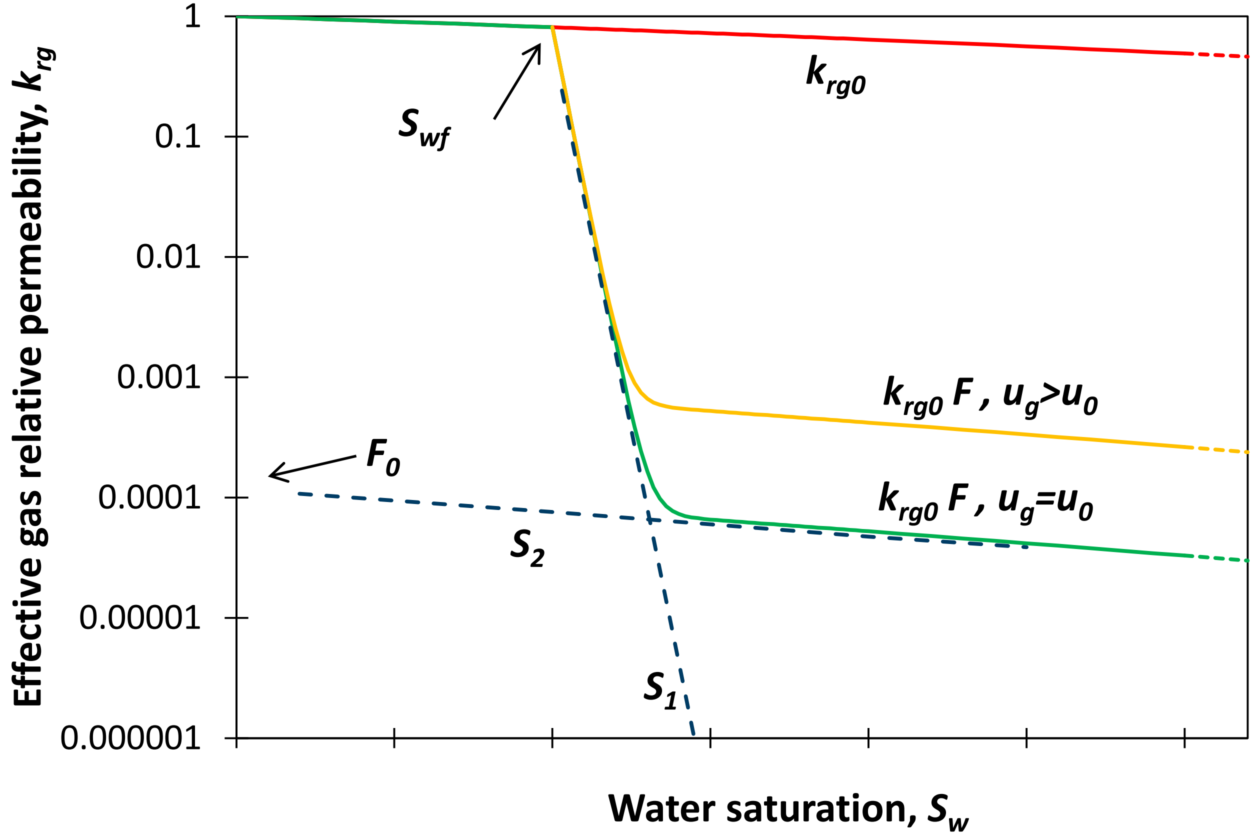


SINTEF foam model

$$F_s = exp\left(\left(S_{wf} - S_w\right)s_1\right) + \frac{U}{U_0} F_0 exp\left(\left(S_{wf} - S_w\right)s_2\right),$$

$$S_w \geq S_{wf}$$

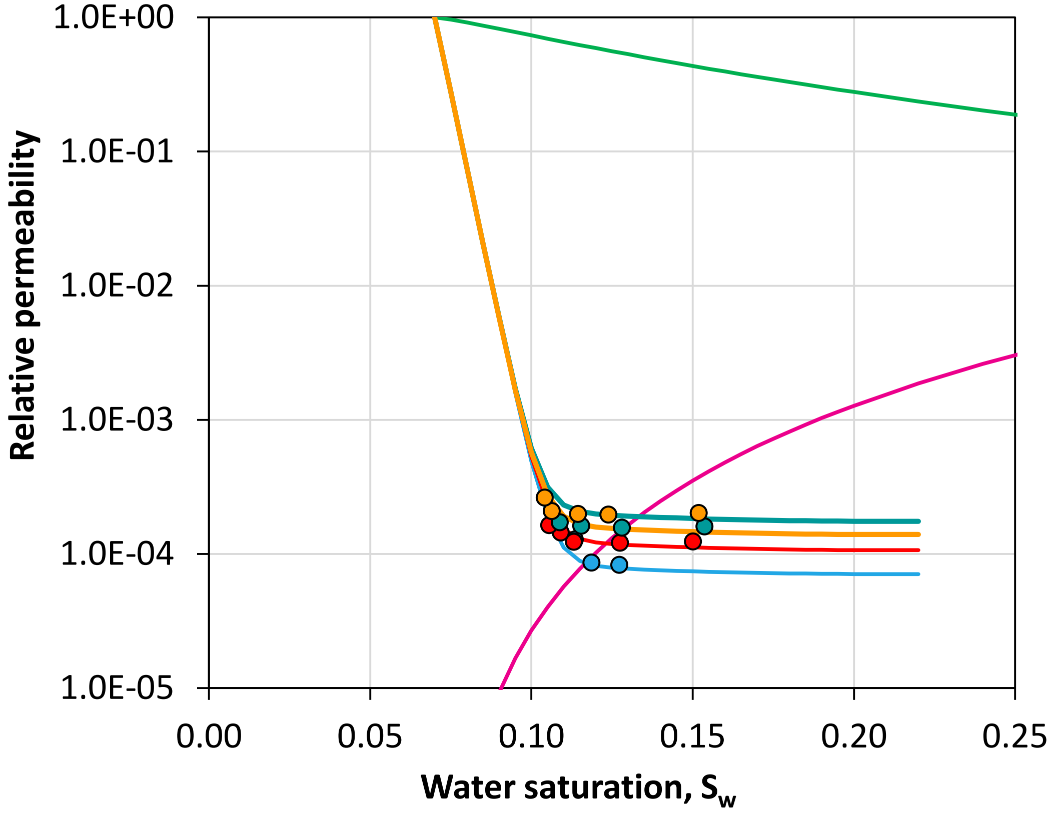
- Combines two regions for gas mobility
  - Foam at the limiting capillary pressure
  - Foam at the limiting pressure gradient
  - No foam below a threshold water saturation, S_{wf}
  - The gas relative permeability is found by multiplying the gas relative permeability by a mobility multiplier, F_s
- Water permeability only a function of water saturation



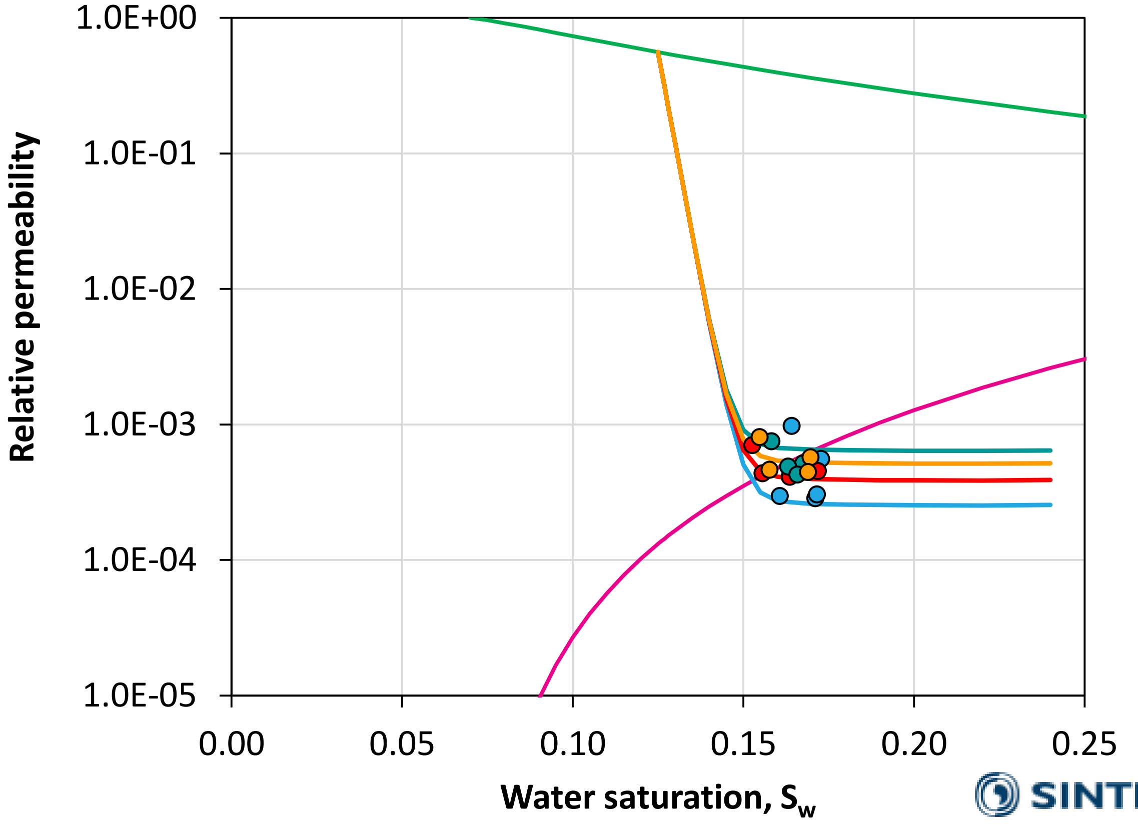
Vassenden, F., and T. Holt. *SPE Res. Eval. & Eng.* 3, no. 2 (2000): 179-85.

CO_2 relative permeabilities with foam

CO_2 relative permeability with C_{14-16}AOS foam



CO_2 relative permeability with Brij L23 foam



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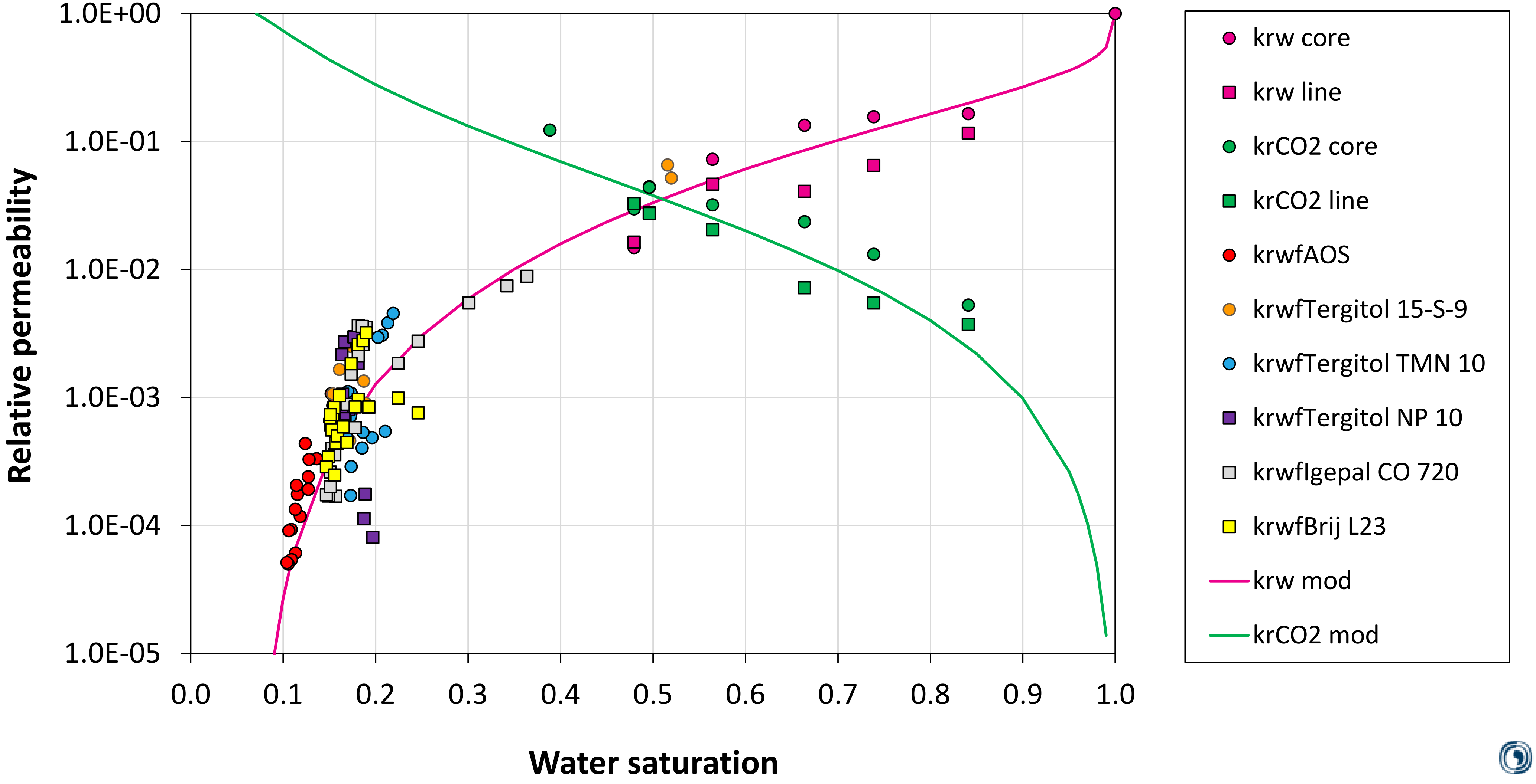
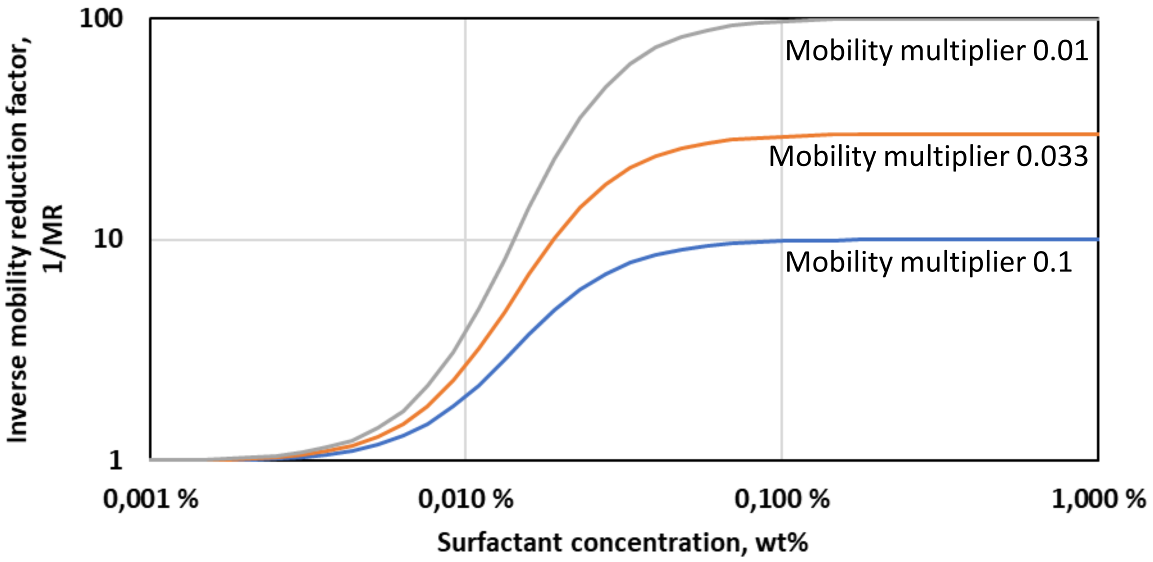
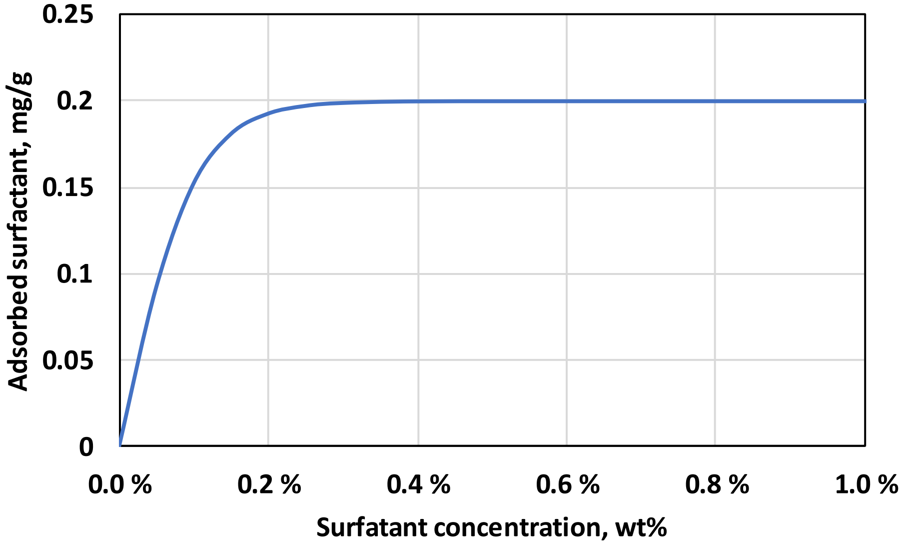
Water and CO_2 (no foam) relative permeabilities



Foam formulation

- Mobility multiplier
  - F_0 = 0.1, 0.033, 0.01
- Dry-out saturation, S_{wf}
  - Below residual water saturation
- Surfactant concentration dependence
  - Constant foam strength above threshold, drops gradually to zero below threshold
- Adsorption to rock
  - Linear increase for low concentrations, constant above threshold concentration
- Partitioning





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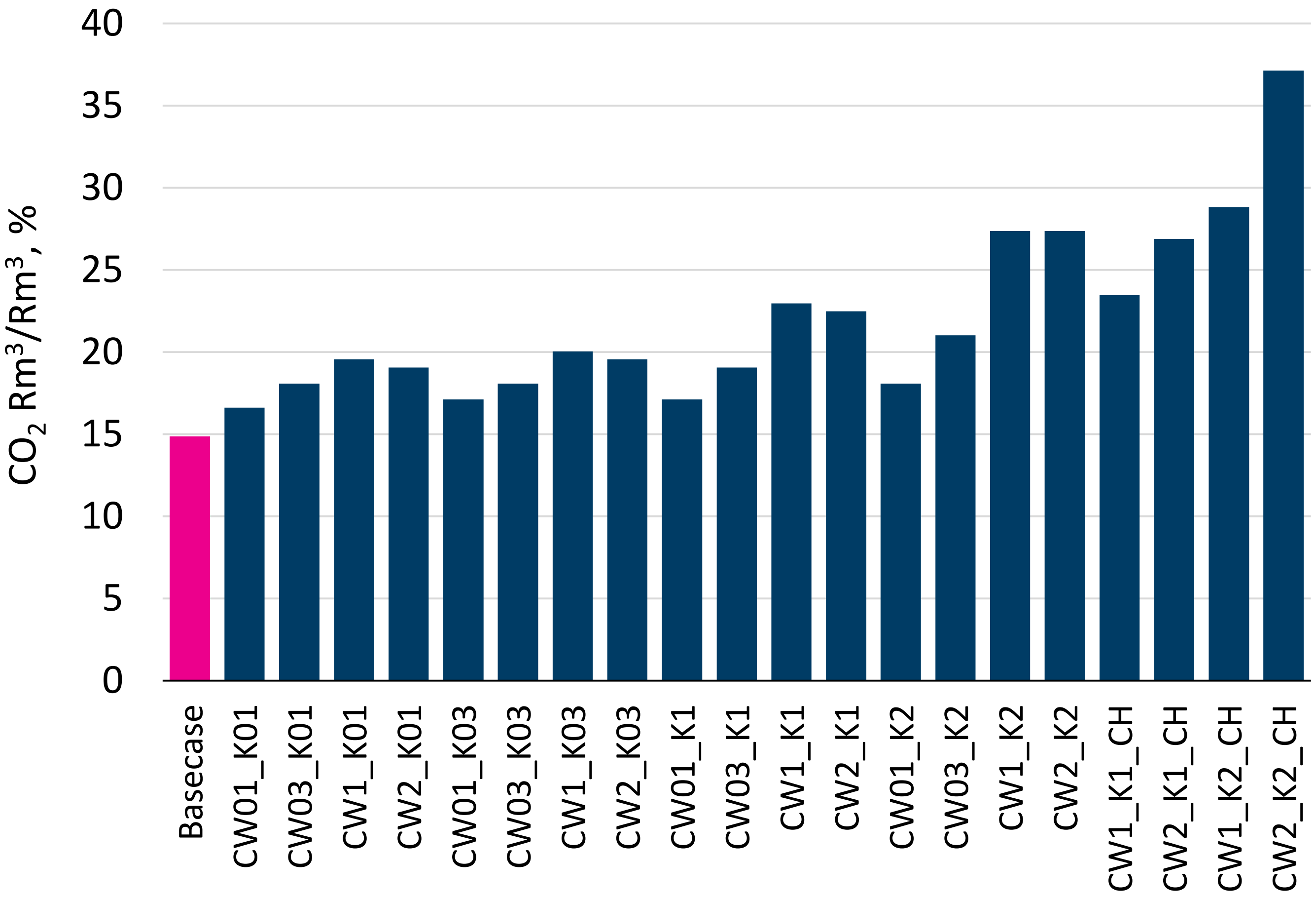
Simulation - Parameters

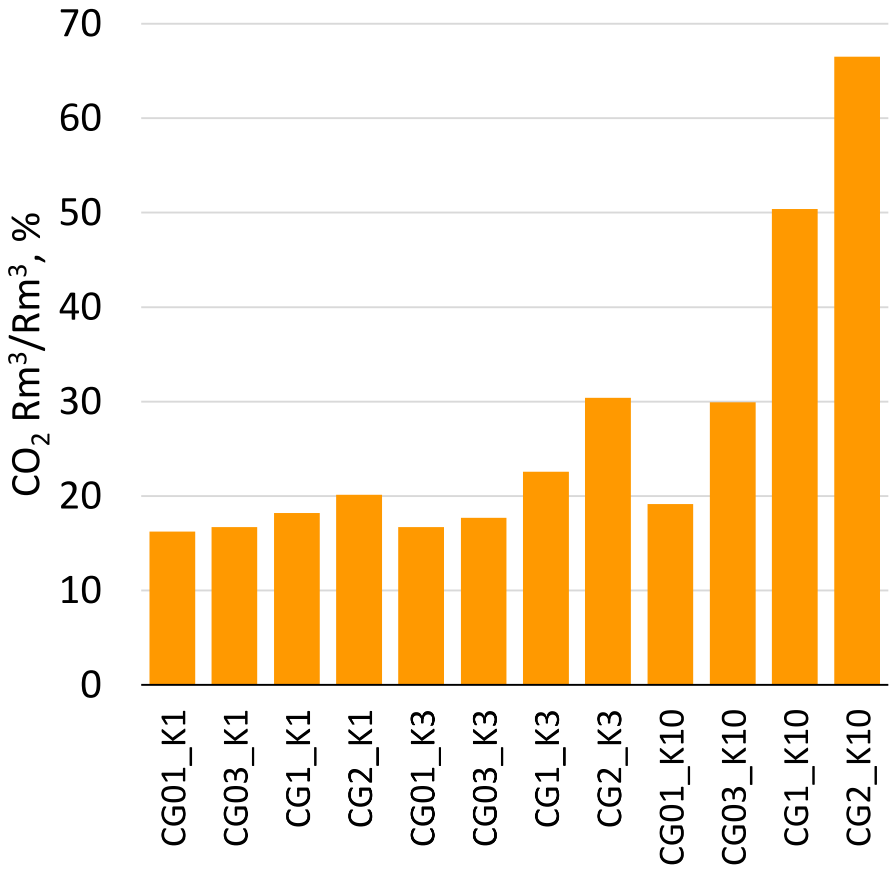
- Surfactant injection period
- Injection strategy
  - Pre slug in water phase
  - CO_2 phase

Parameter	Values
Surfactant placement	Dissolved in brine pre-slug or dissolved in CO_2
Surfactant injection period	2.67 years when injected in brine, 4 years when injected in CO_2
Injected surfactant concentration	0.1, 0.3, 1.0, 2.0 wt.% in injected phase
Partition coefficient	0.1, 0.3, 1.0, 2.0 when injected in brine, 1.0, 3.0, 10.0 when injected in CO_2
Size of simulation unit	1400 m x 1400 m x 100 m

Simulated storage capacities (% of storage capacity)



Water soluble surfactant



CO_2 soluble surfactant

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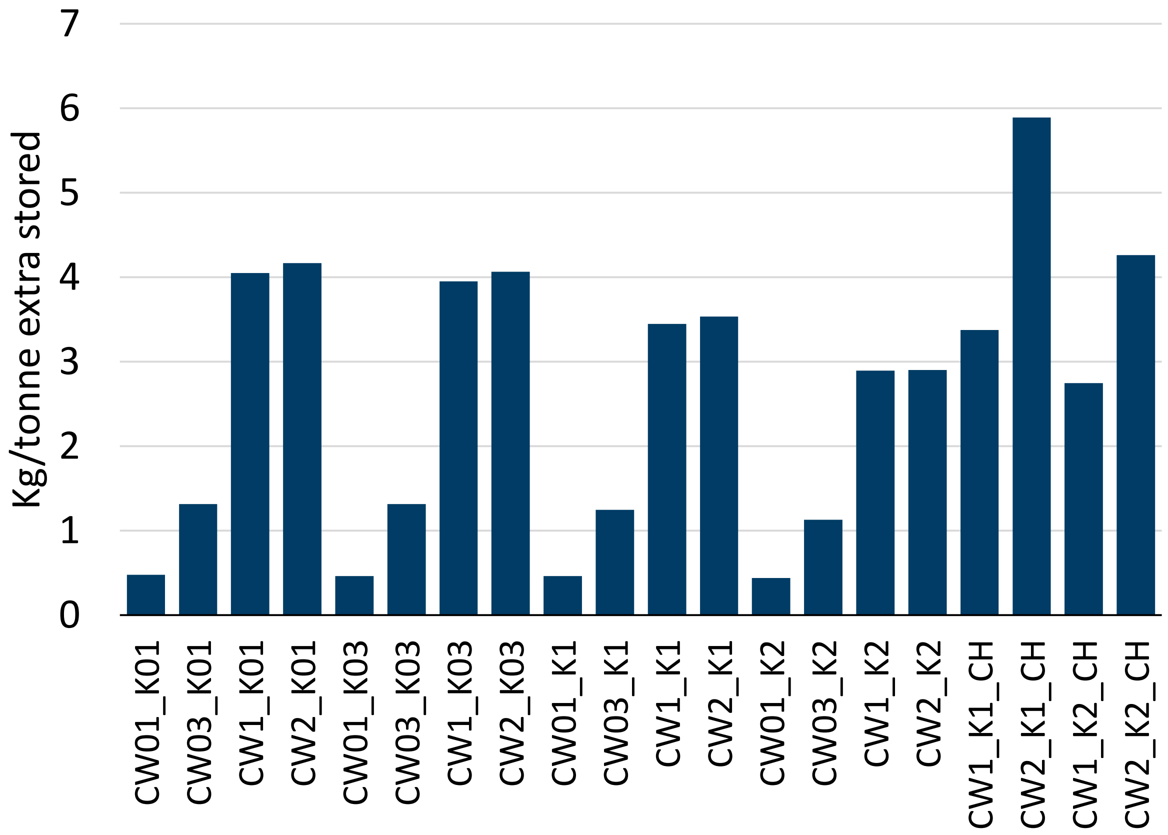
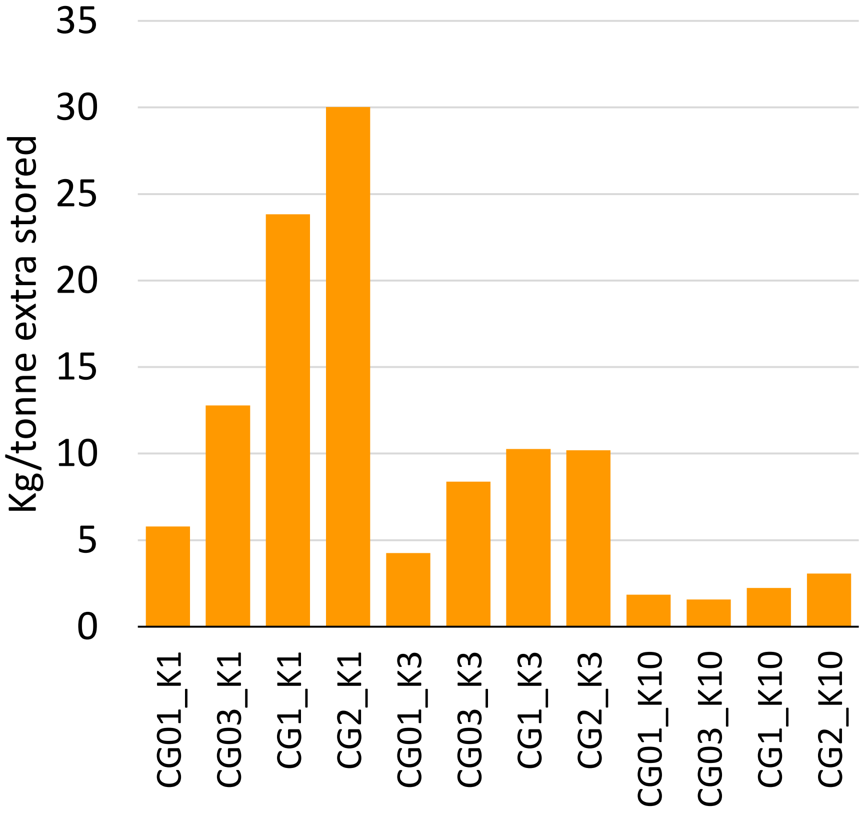
Simulated usage of surfactant (Kg surfactant/tonne CO_2 extra stored)



Water soluble surfactant



CO_2 soluble surfactant

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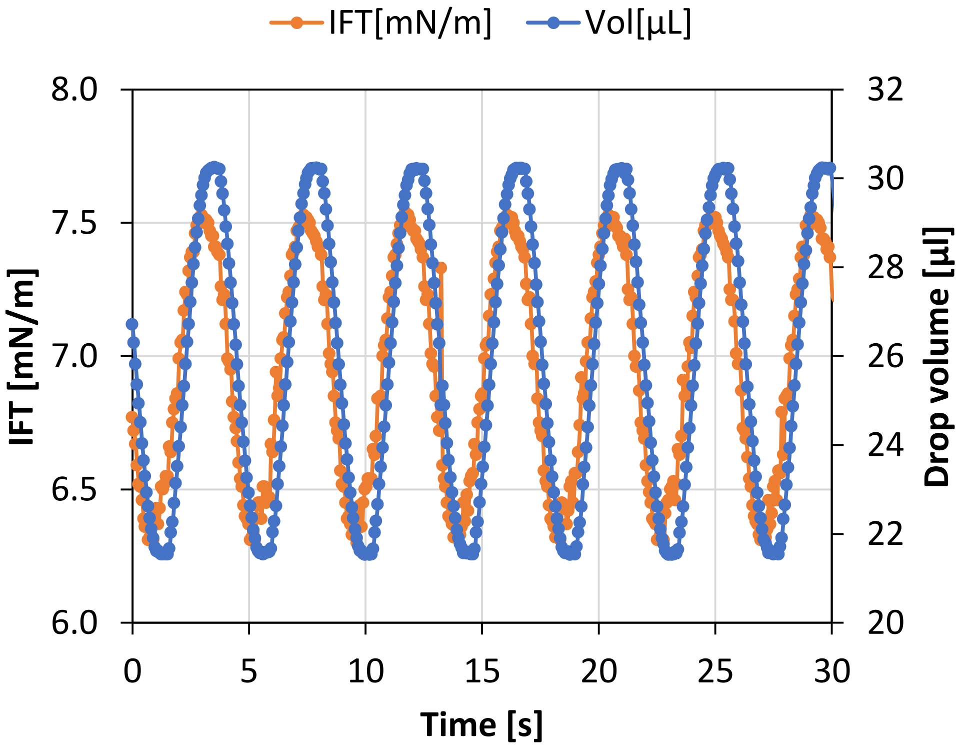
Interfacial rheology by oscillating drop technique

- Novel instrument has been developed
  - Up to 750 bar and 200 °C
  - Cooperation with DataPhysics
- Measurements
  - IFT
  - Interfacial elasticity, E'
  - Interfacial viscosity, E''

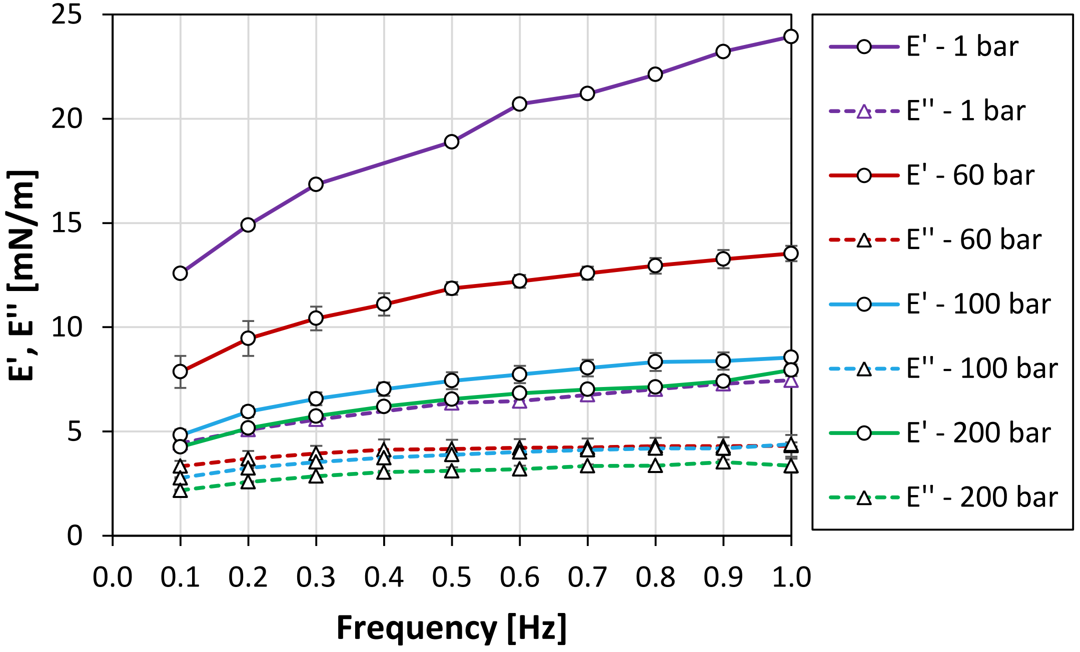


Example of measurement at 300 bar, 25 °C

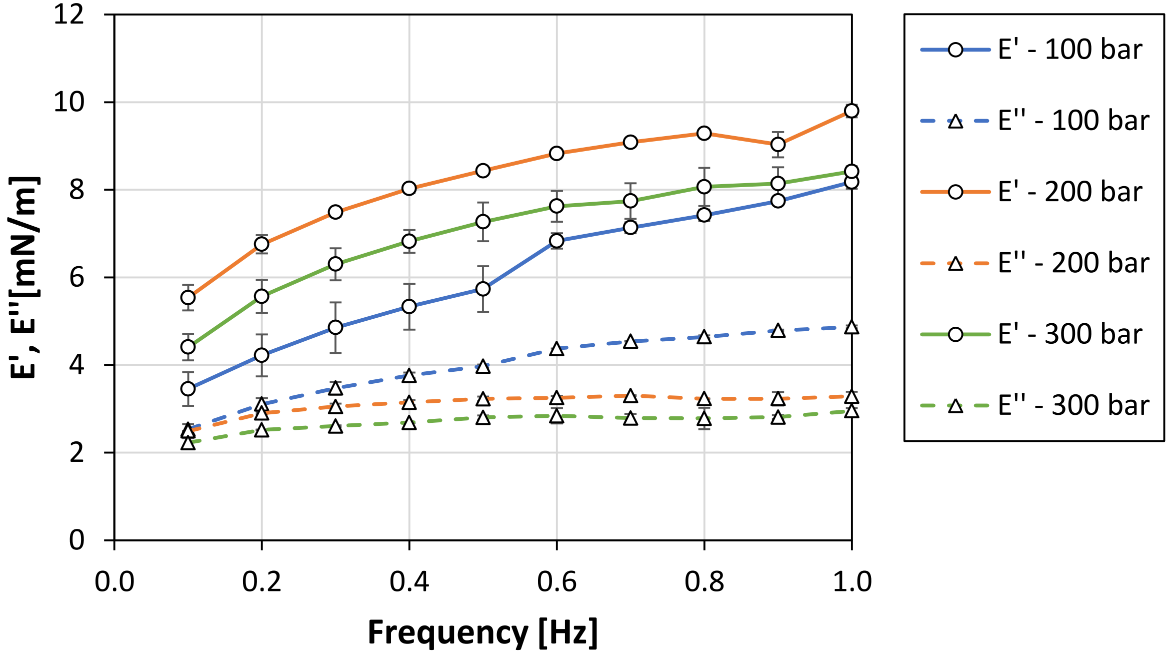
Interfacial rheology by oscillating drop technique

- Initial results

25 °C



40 °C



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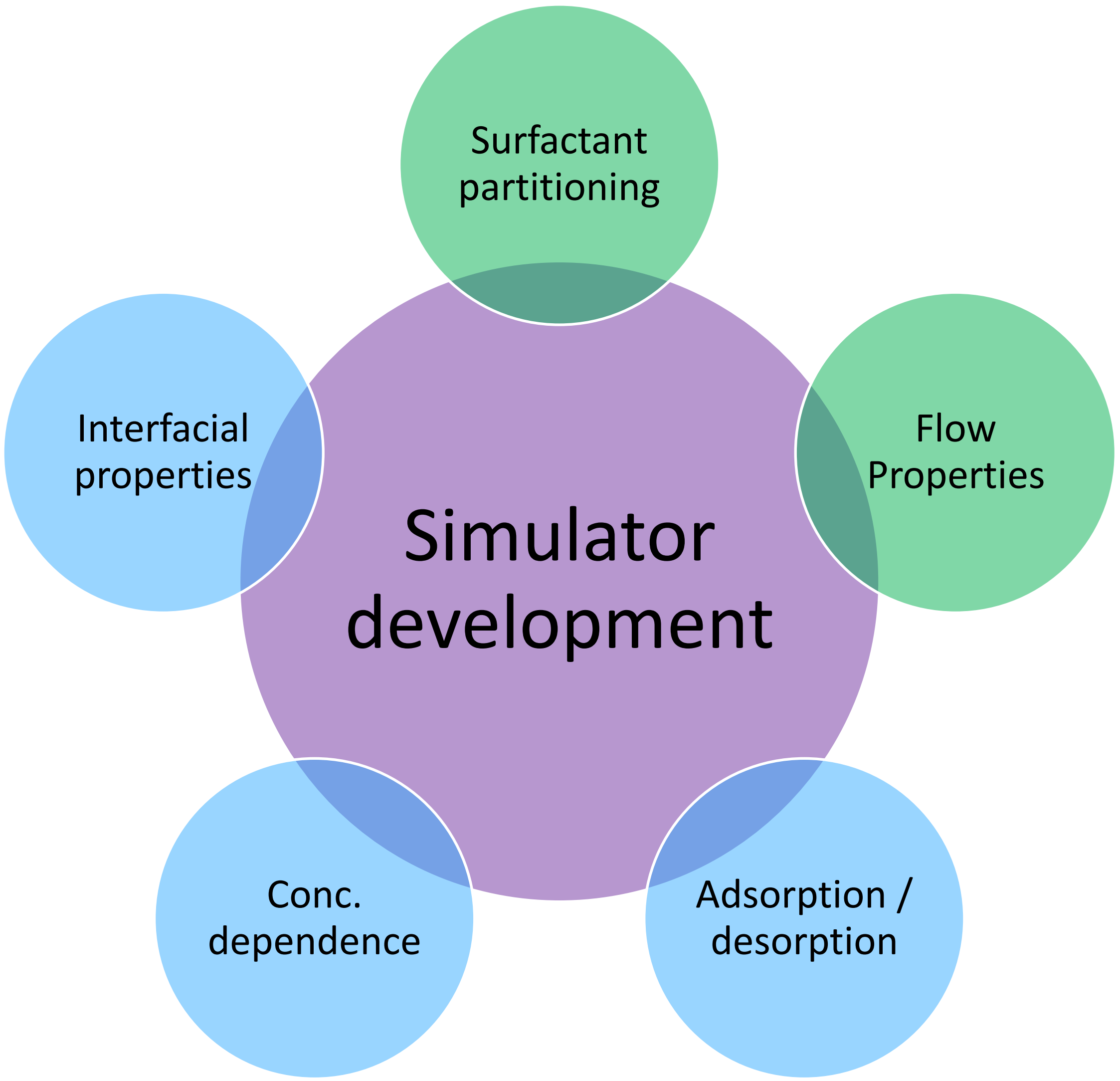
Summary


Surfactant partitioning
Interfacial properties
Flow Properties
Simulator development
Conc. dependence
Adsorption / desorption

Acknowledgement

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