Simulation Tools for Predicting IOR Potential on the Norwegian Continental Shelf

Aksel Hiorth

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IOR Norway 2018 UiS 26. April 2018

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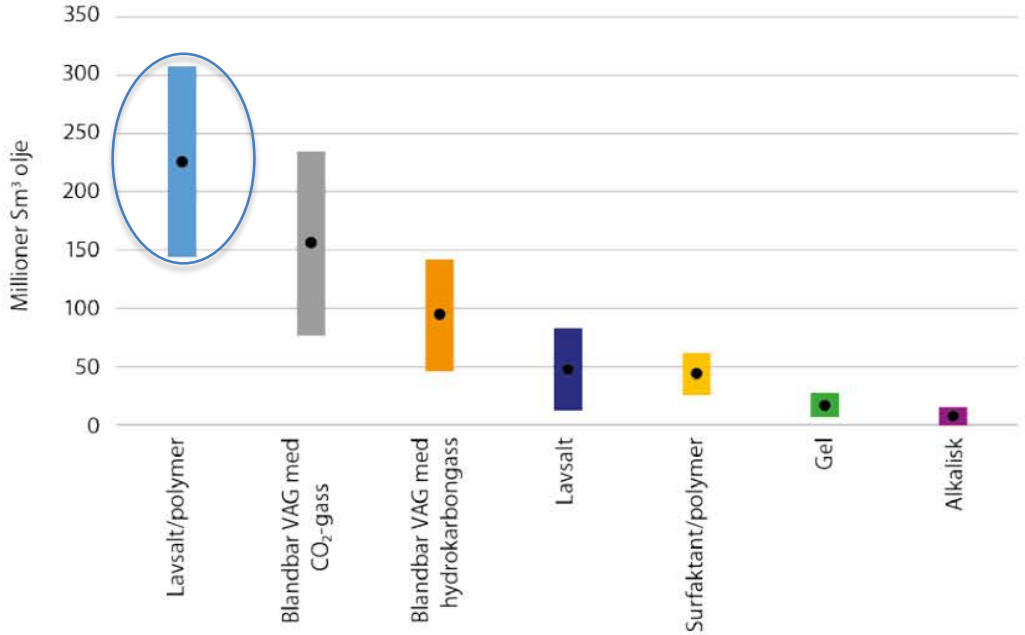
EOR-METODER

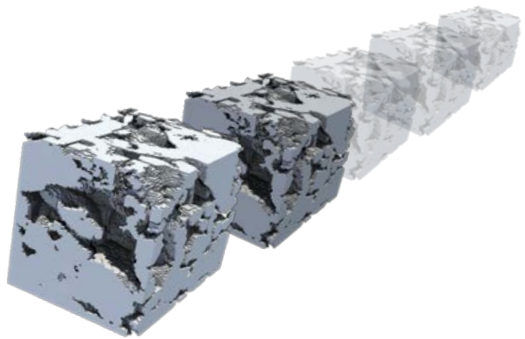
27 felt, 7 metoder:

Resource Report, NPD, 15. June 2017

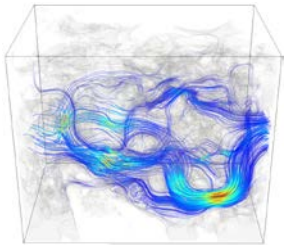
Polymer & low Sal



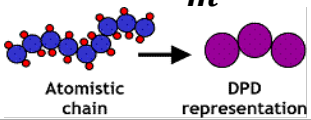
Upscaling



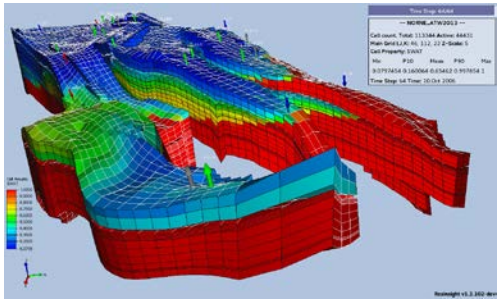
$$\boldsymbol{u_t} - \nabla \cdot \boldsymbol{S}(\boldsymbol{Du}) + (\nabla \boldsymbol{u})\boldsymbol{u} + \nabla \boldsymbol{P} = \boldsymbol{f}$$



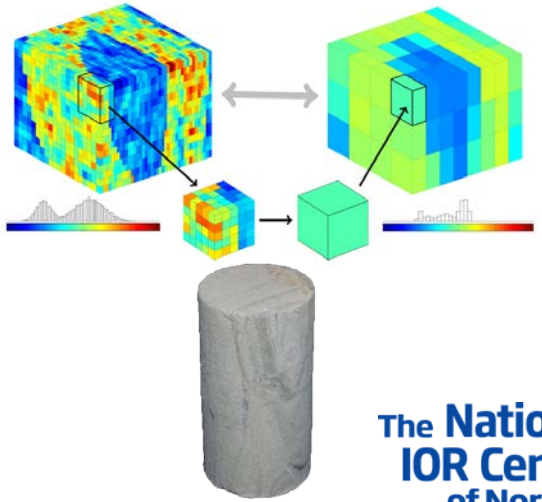
$\overrightarrow{\boldsymbol{F_m}}$



Integrate degrees of freedom



$$k_{rw} = f(r_p, \overrightarrow{\boldsymbol{F_m}}, k_{frac}, q, ..)$$



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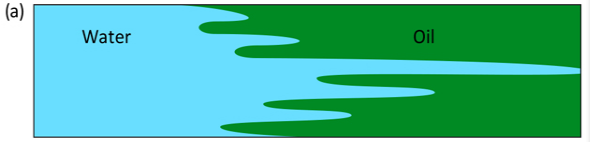
Polymer @ NCS

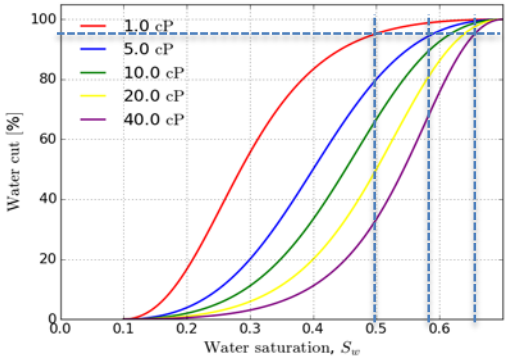
Challenges

- Environmental concerns
- Produced water
- High flow rates
  - Mechanical degradation
- Simulation models
  - Design & potential

Opportunities

- Improve sweep
- Increased oil production
- Less water injected





http://www.npd.no/en/Publications/Resource-Reports/2014/Chapter-2/

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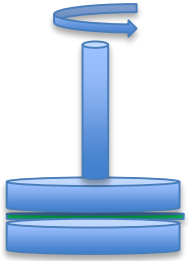
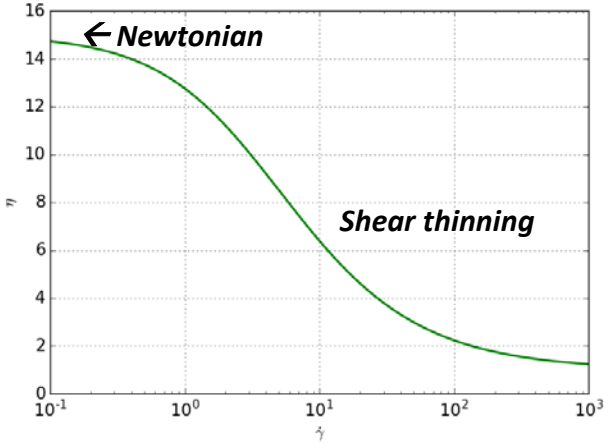
Polymer solutions display complicated rheological behaviour

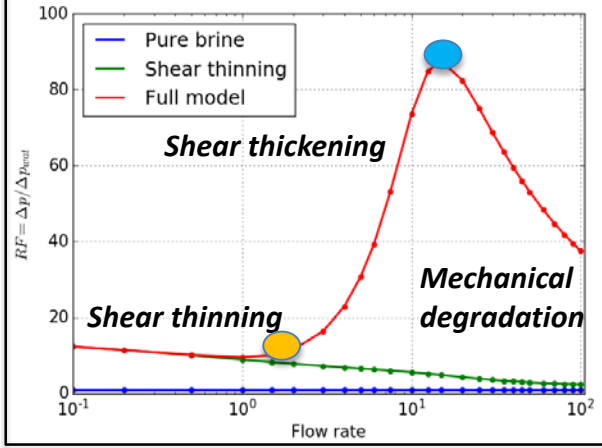


Bulk viscosity in a rheometer



$$RF = \frac{\lambda_{water}}{\lambda} = \frac{\Delta p}{\Delta p_{water}}$$

Mobility reduction in porous media



Onset of shear thickening

$$\lambda_2 = \frac{1}{N_{De}} \frac{1}{5R_g} \frac{\phi}{1-\phi} \frac{\eta_s[\eta]M_w}{T}$$

Onset of Mechanical degradation

$$\frac{dM_w}{dt} = -f_{rup} \cdot M_w$$

$$= -(r_d \cdot \eta \cdot \dot{\gamma})^{\alpha_d} \cdot \frac{2}{R_p} \cdot M_w^{\beta_d} \cdot M_w$$

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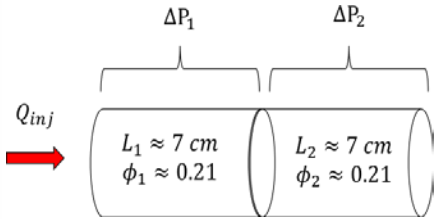
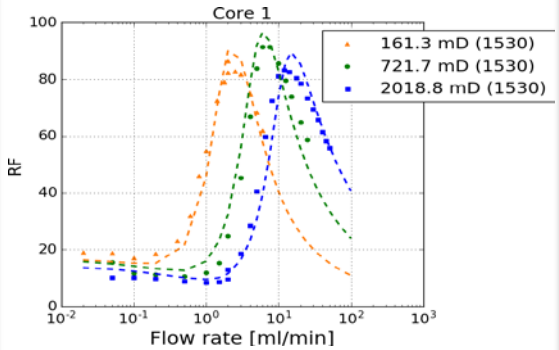
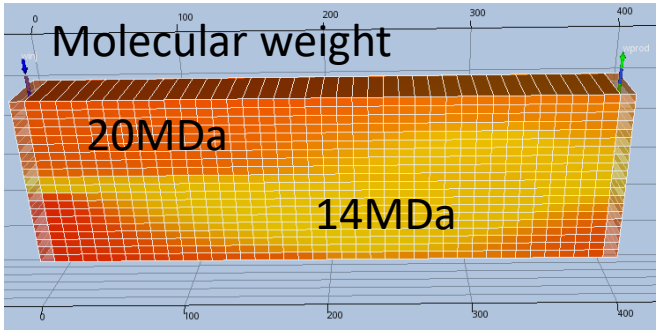
IORCoreSim – Polymer from core to field

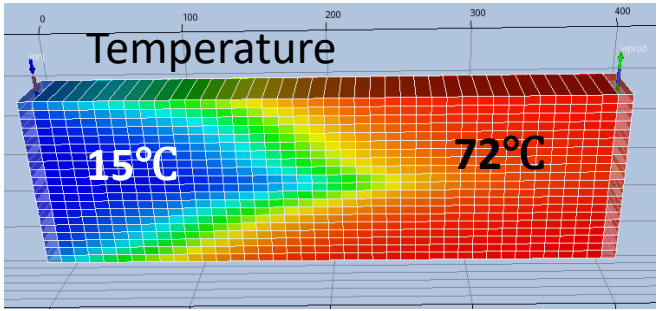
Core Scale Callibration





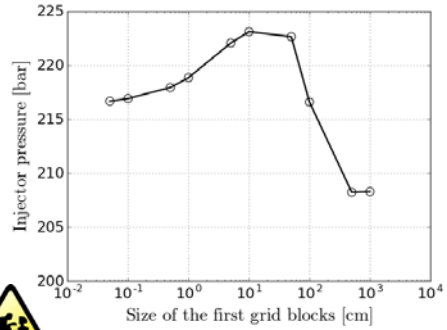
Larger scale





Fine grid needed

- Predict correct well pressure
- Field degradation



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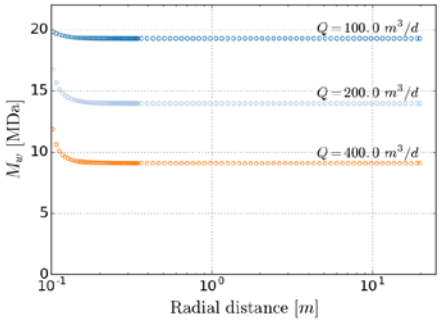
We understand the main behavior of polymers

- Core scale experimental procedures
- Models to interpret
- Large scale behavior “simple”
  - Well model needs to be improved in simulators
  - Reservoir behavior “simple” shear thinning



Refs:

Lohne, A., Nødland, O., Stavland, A. and Hiorth, A. [2017] *A model for non-Newtonian flow in porous media at different flow regimes*. Comp. Geosc., 1–24.

Nødland O., Lohne, A., Stavland, A. and Hiorth, A. [2018] *A model for non-Newtonian flow in porous media at different flow regimes*. EAGE 2017 (sub to TiPM).

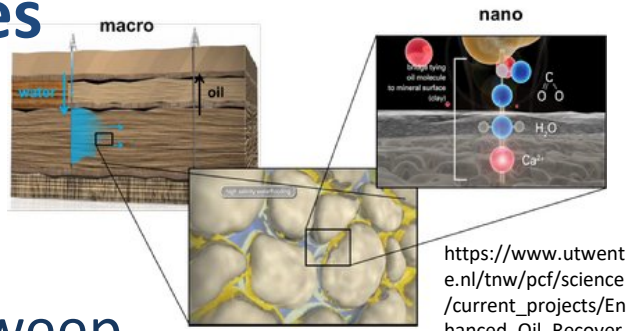
Low salinity @ NCS

Challenges

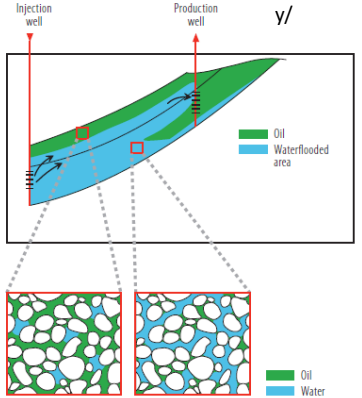
- **Mechanisms**
- Cost of producing water
- Simulation models
  - Design & potential

Opportunities

- Improve microscopic sweep
- Increased oil production
- Less water injected



https://www.utwente.nl/tnw/pcf/science/current_projects/Enhanced_Oil_Recovery/



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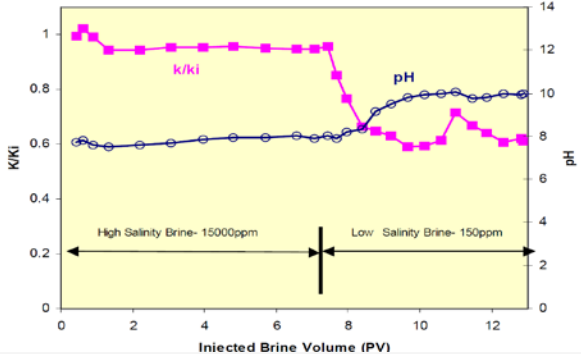
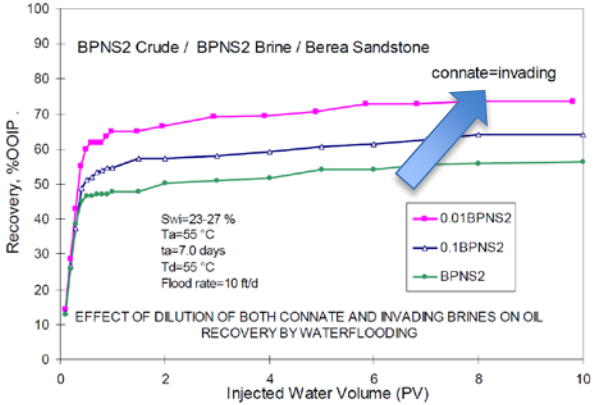
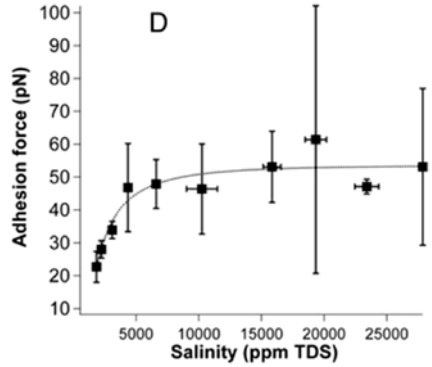
Core



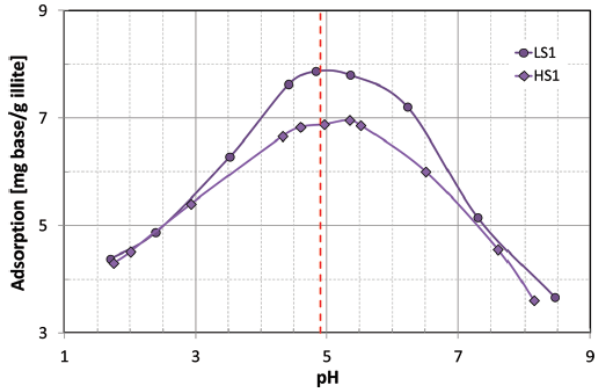


McGuire, P. L. et al. (2005) SPE 93903-MS

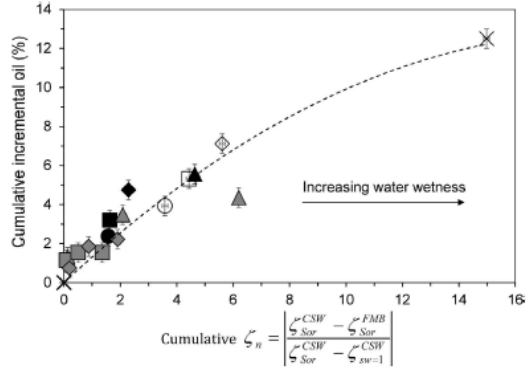
Pore Mechanisms



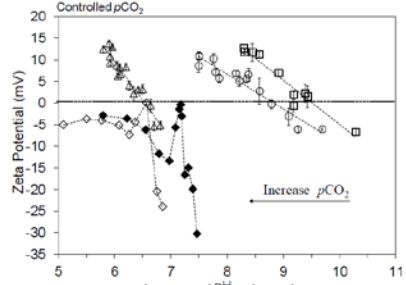
Hilner et al. Scientific Reports (2015)5:9933



Aksulu et al. Energy Fuels (2012), 26, 3497−3503



Jackson et al. Scientific reports (2016) 6: 37363.



Dawoud, A. PhD thesis 2017

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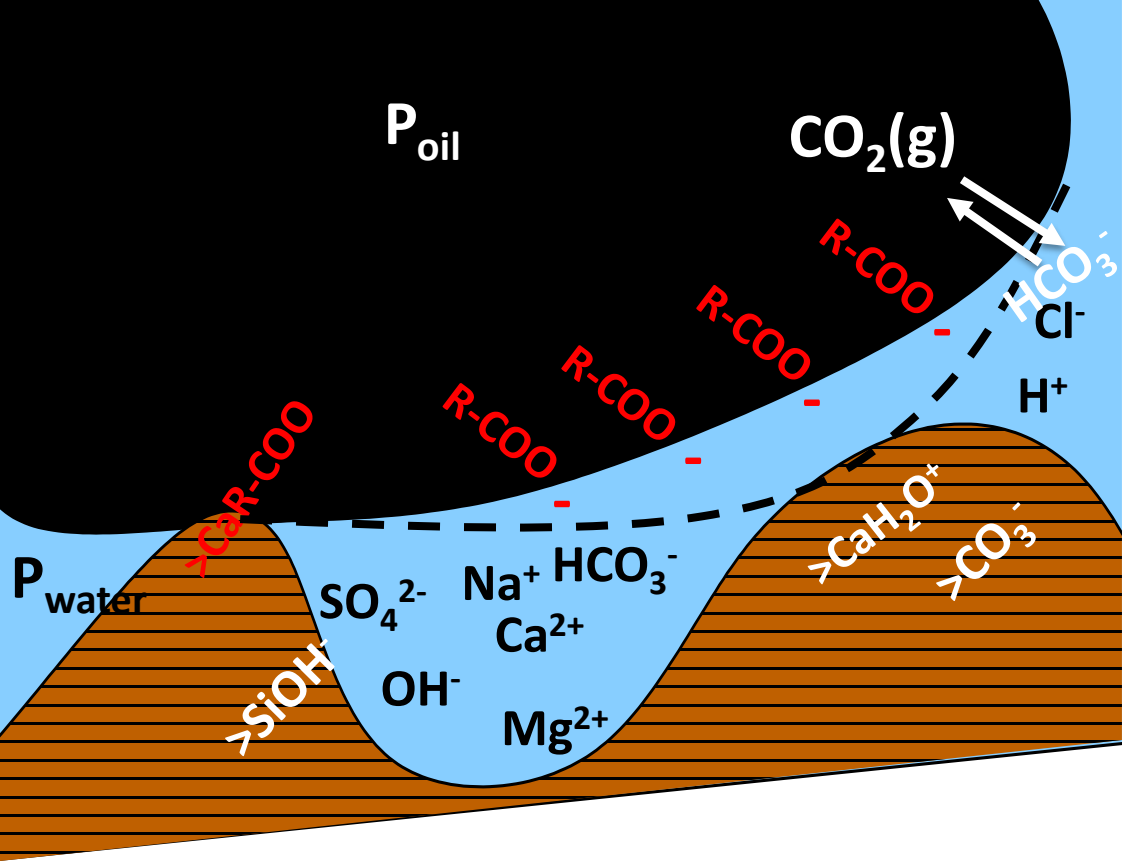

Salinity, pH, surface potential is important

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What about the Upscaling ??

- **10% Additional on Core Scale → maybe 2-3% field?**
- **If it works, why care about the mechanisms?**
  - Field vs core pH?
  - Field vs core surface potential?

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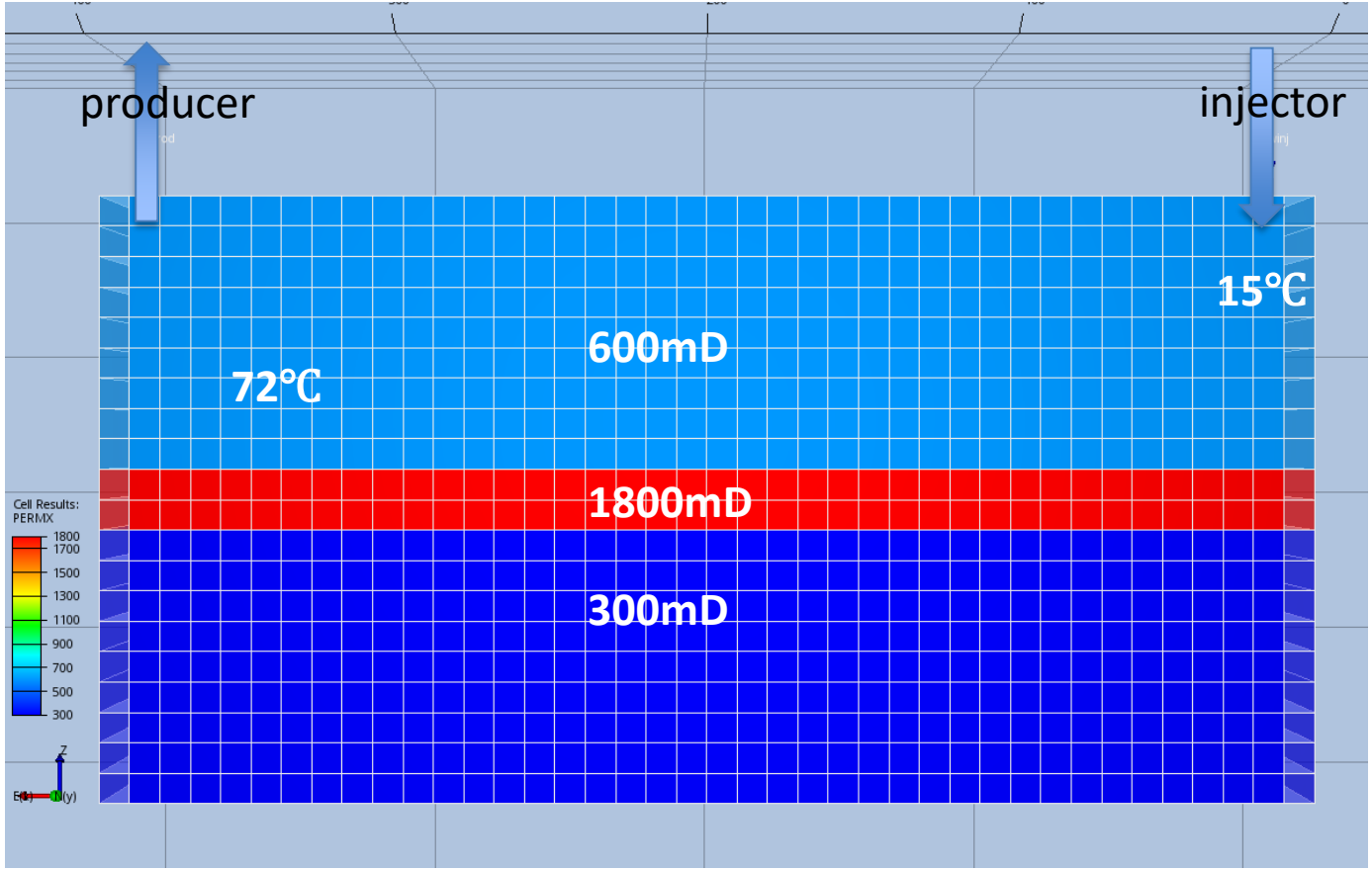
IORCoreSim - Synthethic model



Two cases:
1. 0.1wt% CO_2 in oil
2. 10^{-4}wt% CO_2 in oil

After 600 days switch from seawater to LowSal

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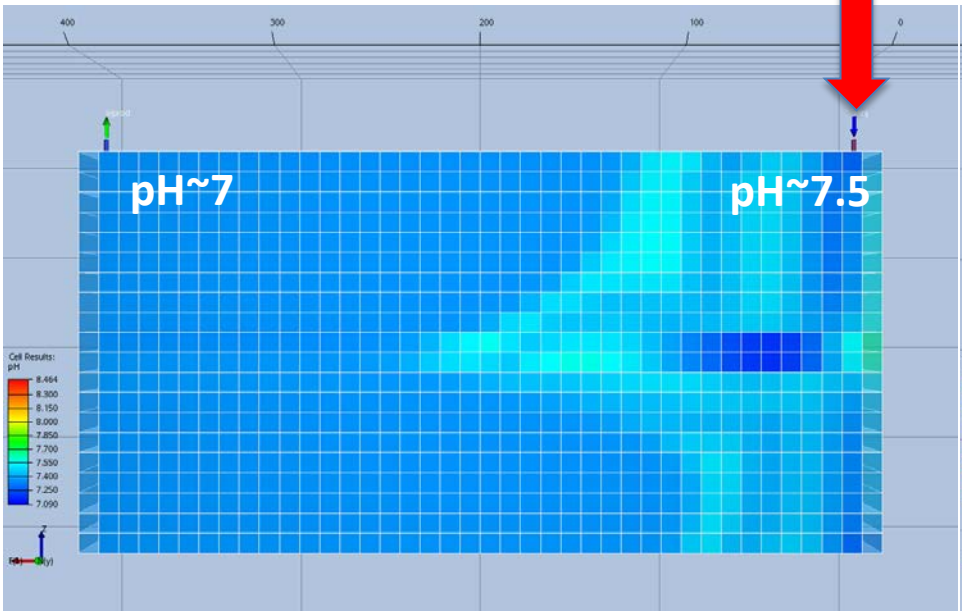
Field pH depends on CO_2 in oil & calcite

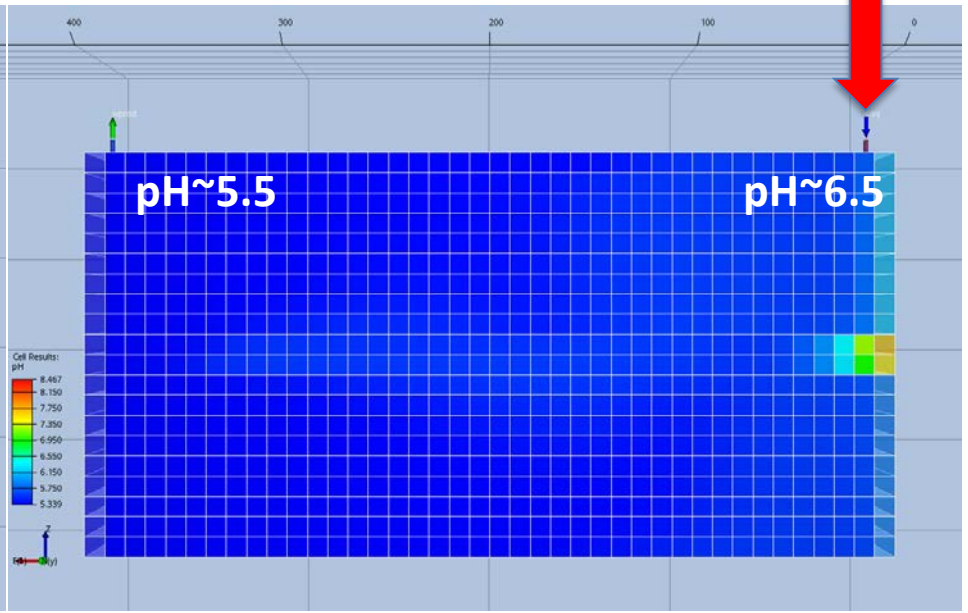
10^{-4} wt% CO_2 in oil

High sal



0.1 wt% CO_2 in oil

High sal



t=300 days

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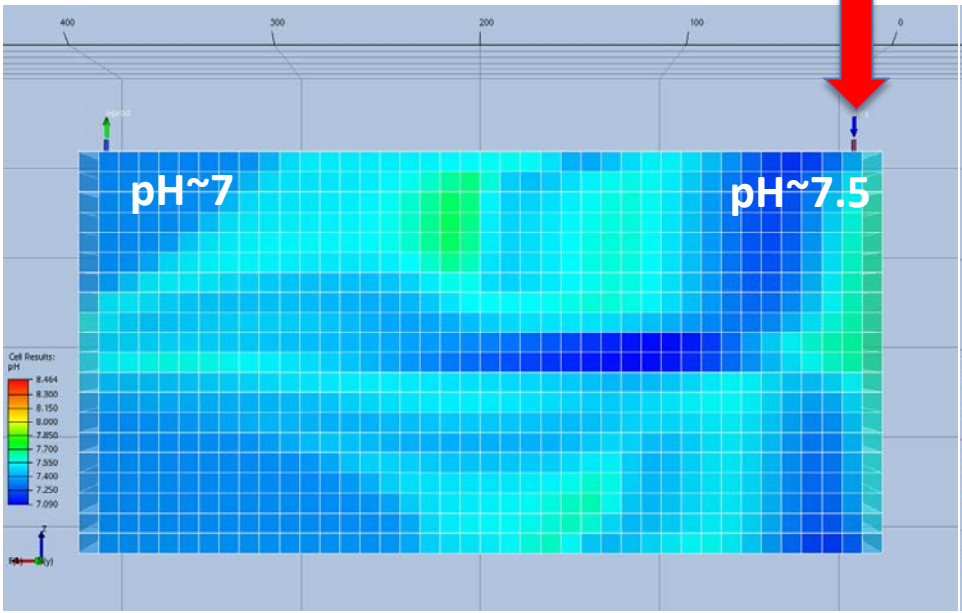
Field pH depends on CO_2 in oil & calcite

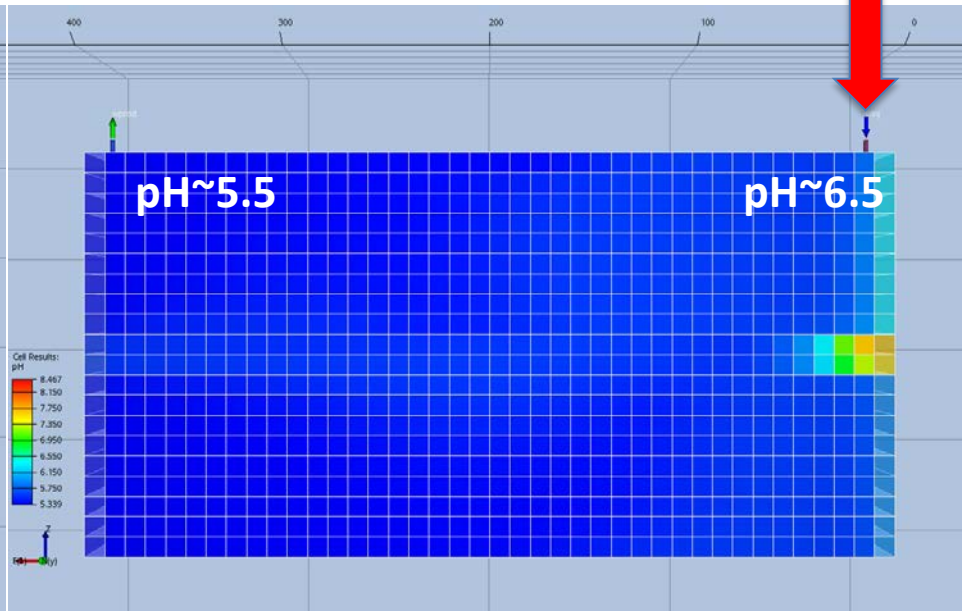
10^{-4} wt% CO_2 in oil

High sal



0.1 wt% CO_2 in oil

High sal



t=500 days

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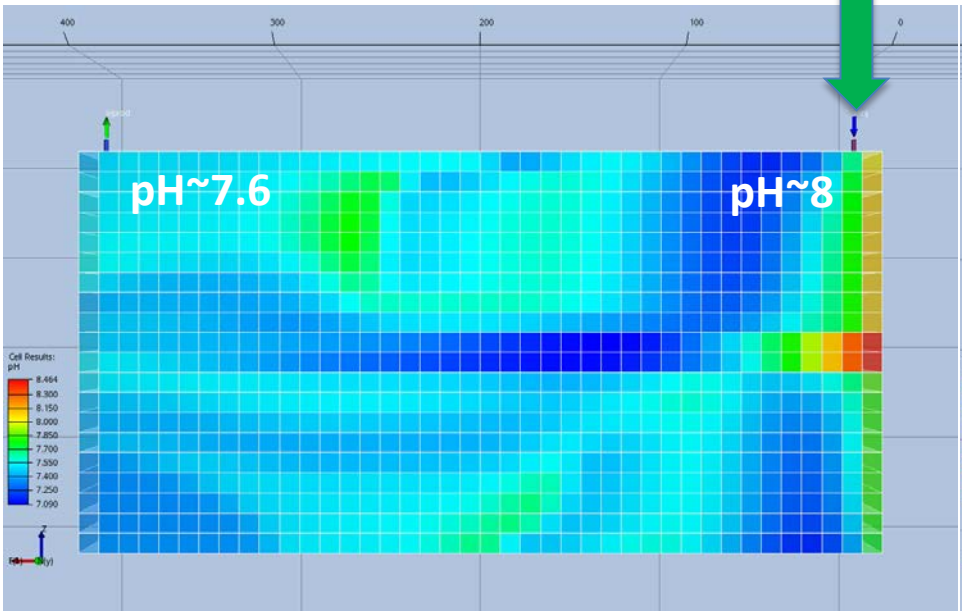
Field pH depends on Co2 in oil & calcite

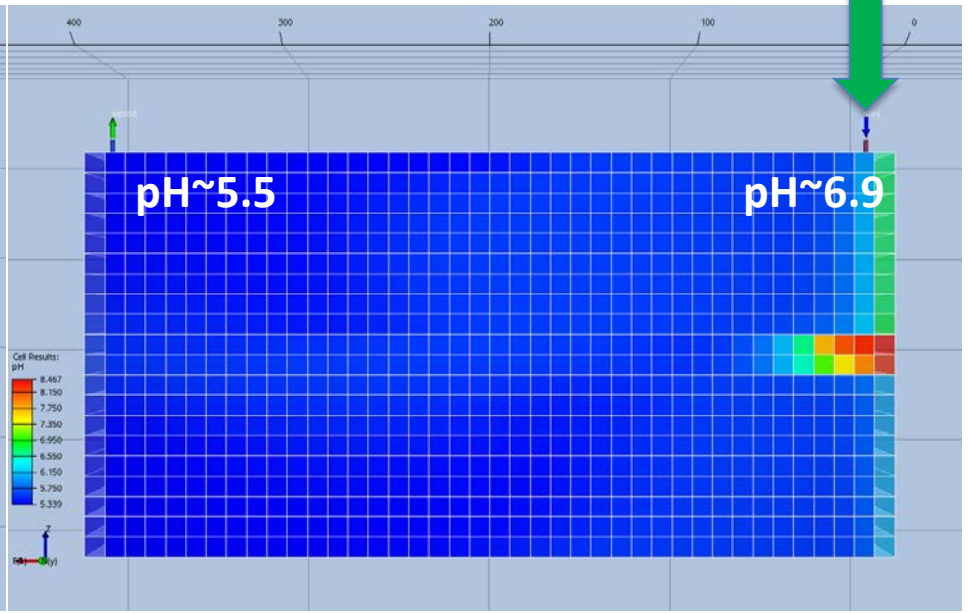
10^{-4} wt% CO_2 in oil

Low sal



0.1 wt% CO_2 in oil

Low sal



t=650 days

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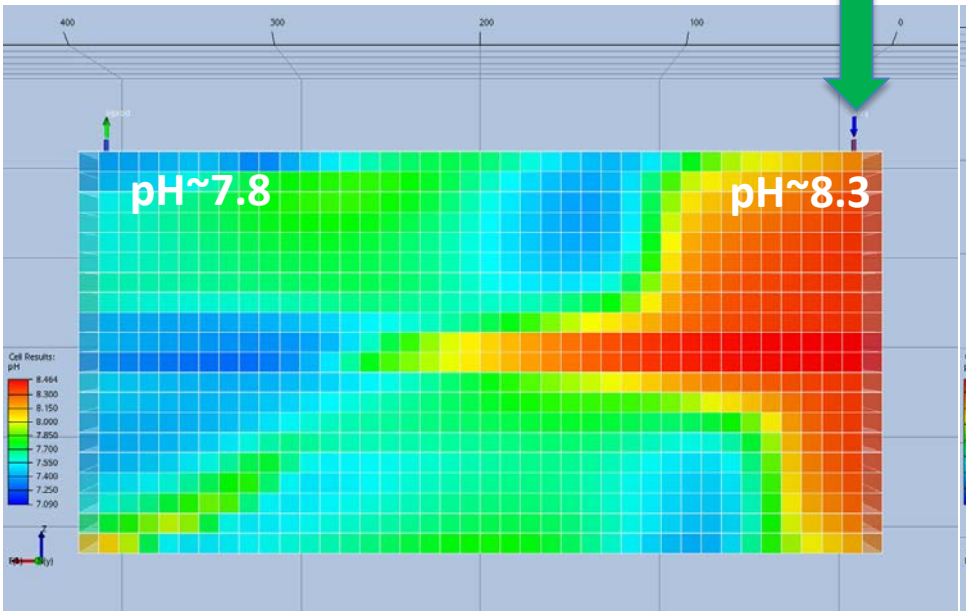
Field pH depends on CO_2 in oil & calcite

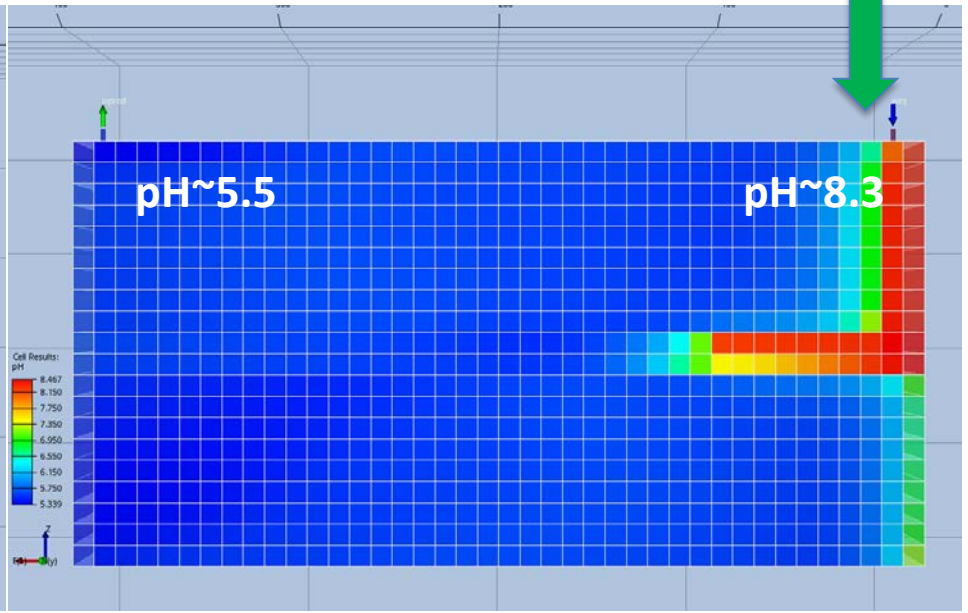
10^{-4} wt% CO_2 in oil

Low sal



0.1 wt% CO_2 in oil

Low sal



t=1400 days

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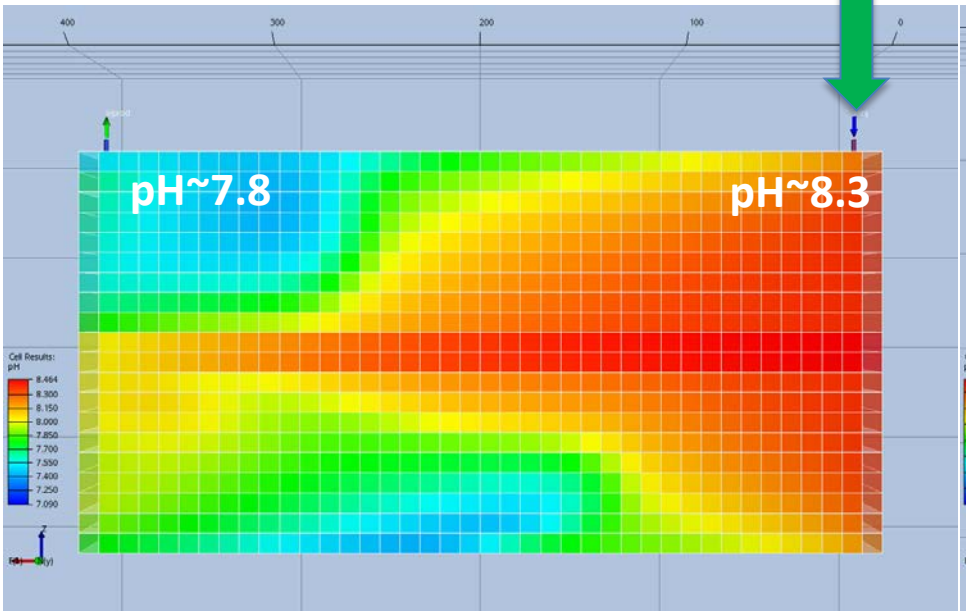
Field pH depends on CO_2 in oil & calcite

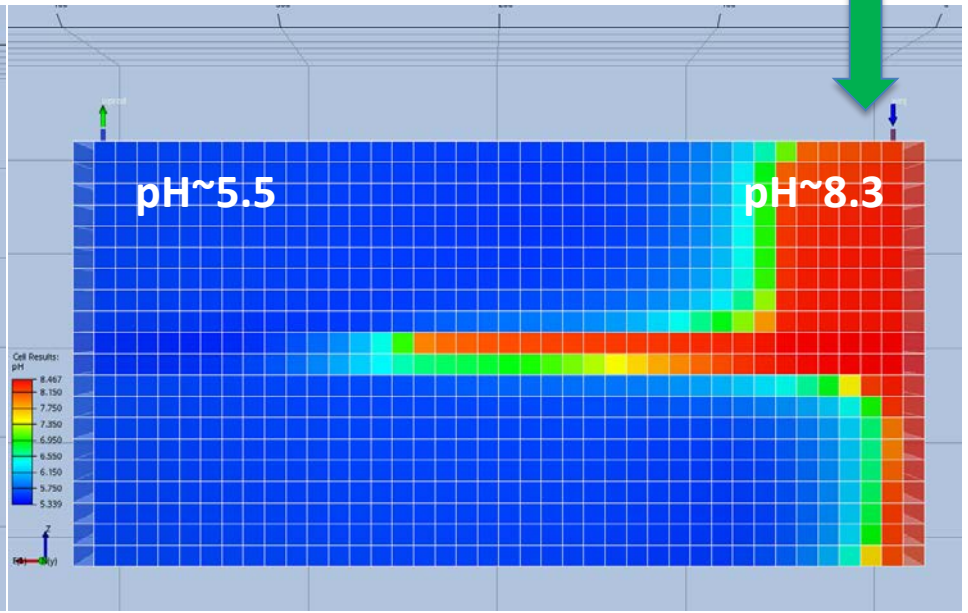
10^{-4} wt% CO_2 in oil

Low sal



0.1 wt% CO_2 in oil

Low sal



t=2850 days

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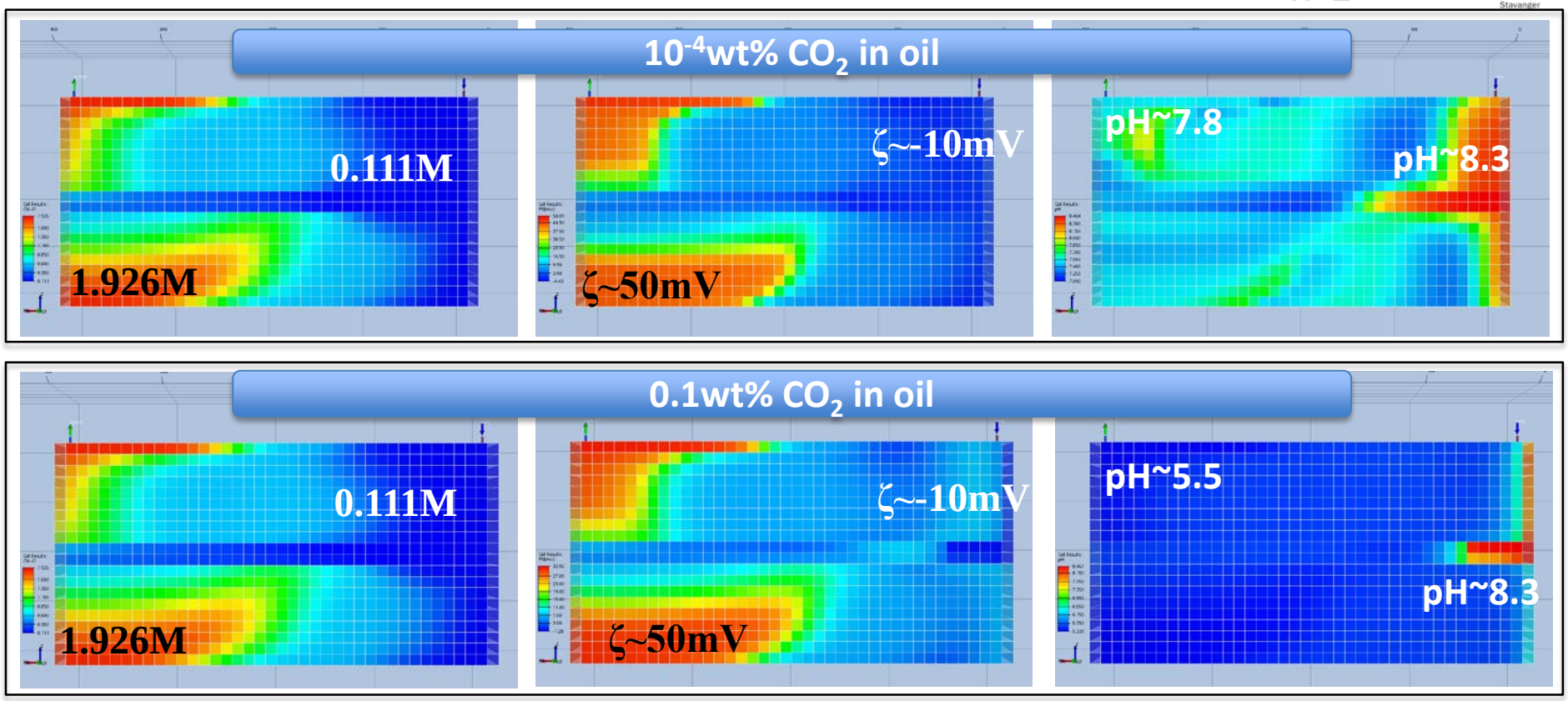
Chlorine Concentration | Surface Potential | pH



(900days) pH, salinity and surface potential - different speeds

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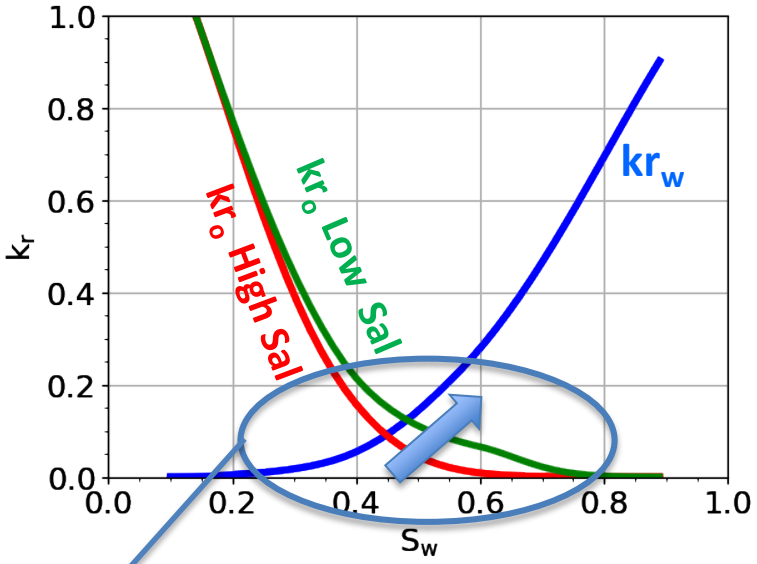
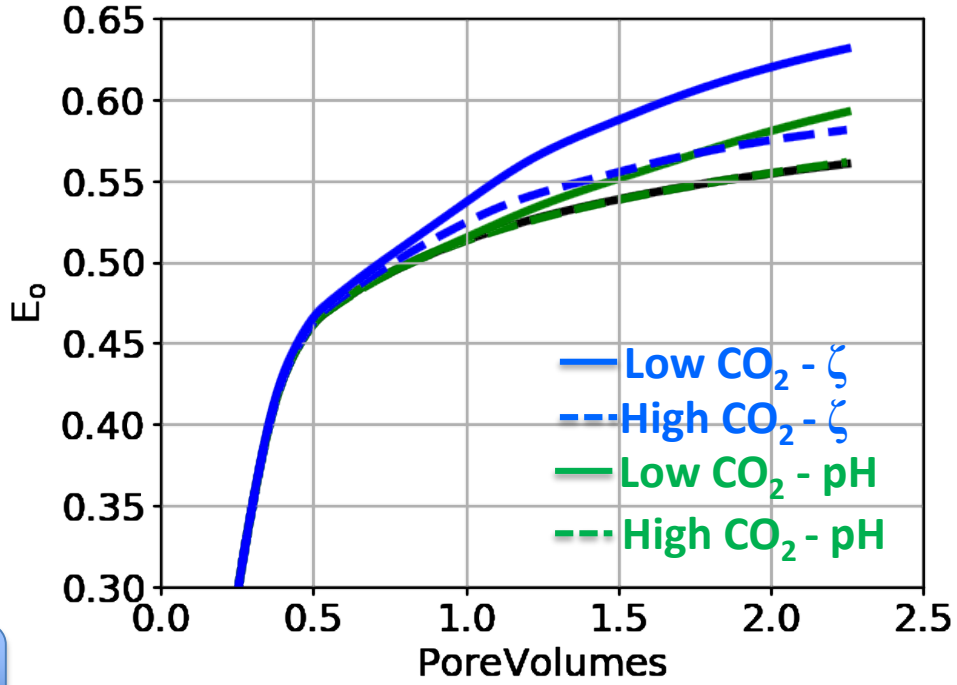
Field Recovery



Case I: pH

Case2: Surface Potential (ζ)



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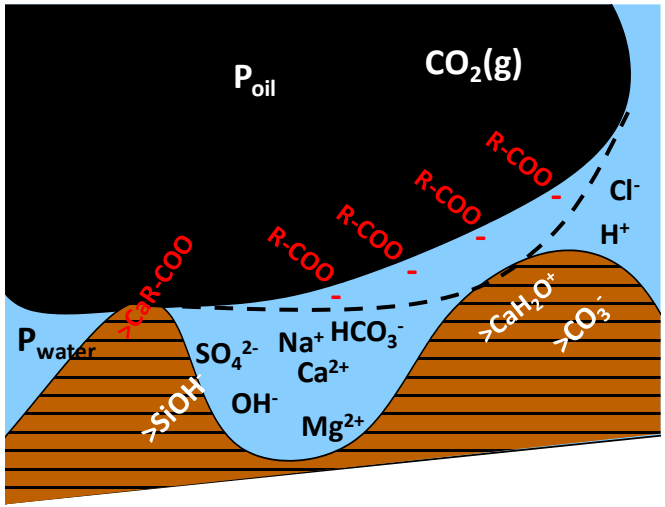
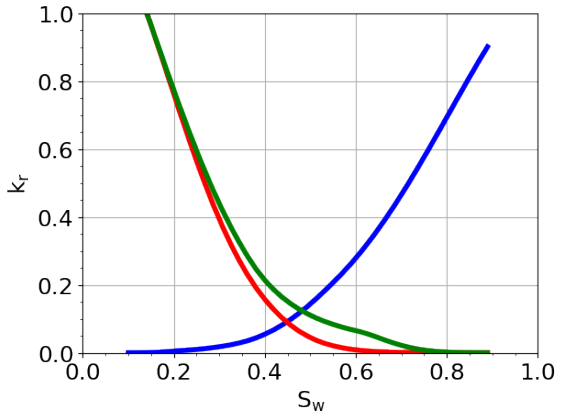
Field response varies greatly

- Mechanisms important
- Pore surface wetting vs production





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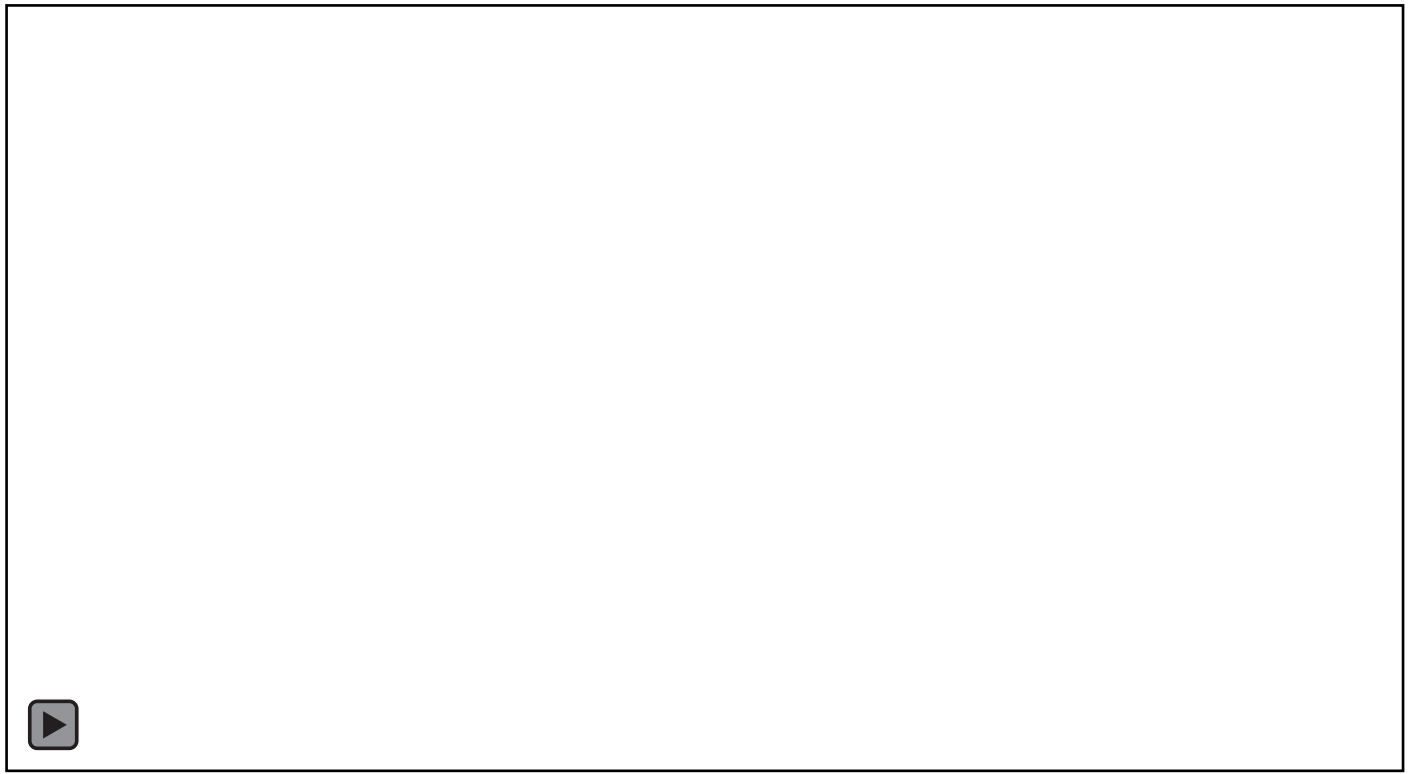
“2D”-Pore Scale Modelling



Oil

High Salinity

$\theta \sim 35^o$

Low Salinity

$\theta \sim 60^o$

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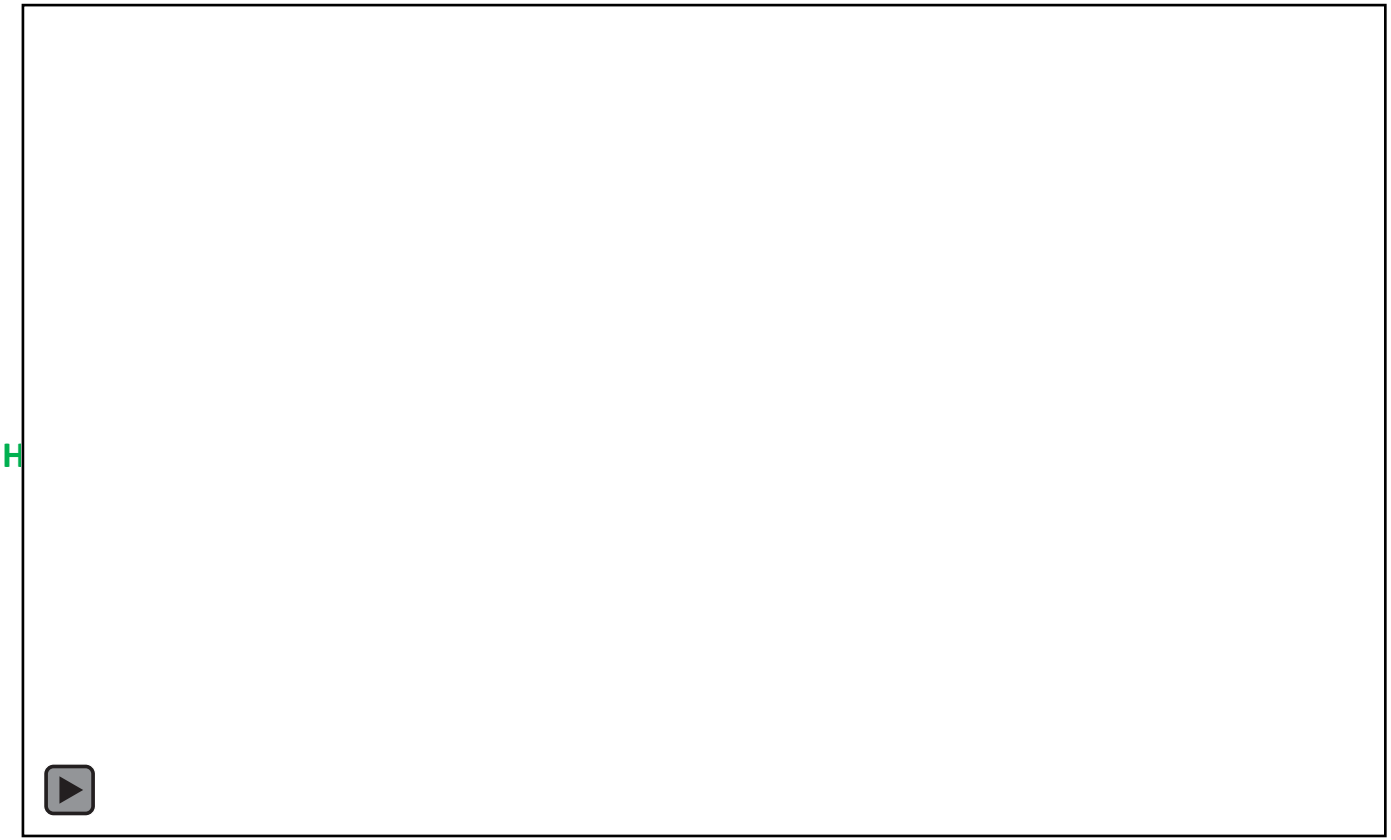
3D Pore Scale Modelling



Oil

High Salinity

$\theta \sim 35^o$

Low Salinity

$\theta \sim 60^o$

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Summarize

- Field design of polymer
  - Tools and experimental procedures ready
- Field design of Low Sal
  - Too much lab work and too little modelling – we are closing the gap
  - Need pore scale understanding

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Acknowledgement

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