Permeability reduction by salt precipitation

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Outline

- Introduction
- Estimate precipitation by simulations
- Flooding experiments to determine permeability reduction during CO_2-injection
  - Effect of formation water composition
  - Core orientation, i.e. displacement efficiency
- Conclusions and Future works

Introduction

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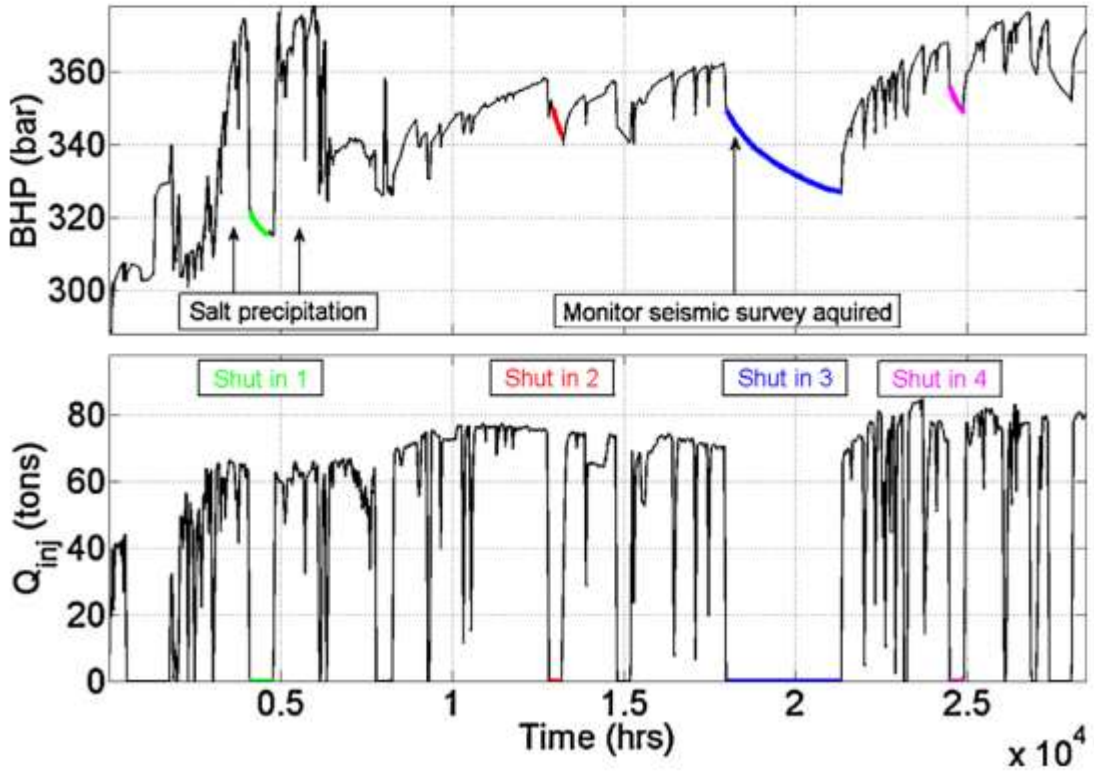
CO$_2$ storage and Injectivity

- Salt precipitation
  - Formation water
  - Completion fluids
- Bacteria activity
- Fines migration
- Temperature and pressure cycling
- Hydrate formation

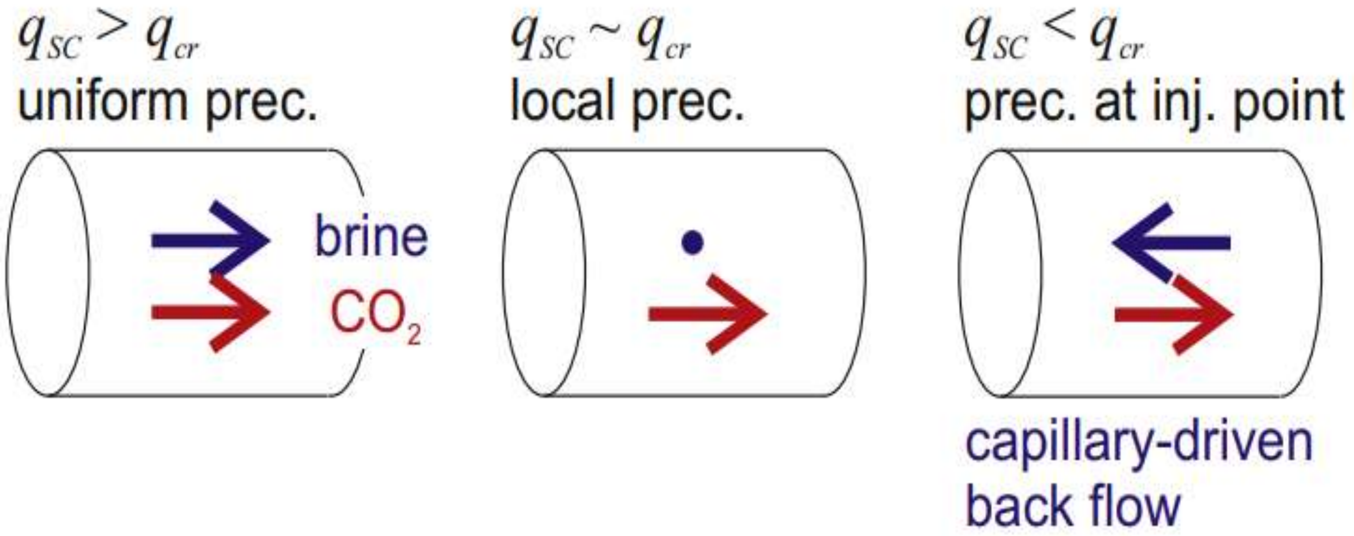
Snøhvit : BHP and flow-rate



Grude, S., M. Landrø, and J. Dvorkin. 2014. 'Pressure effects caused by CO2 injection in the Tubåen Fm., the Snøhvit field', *International Journal of Greenhouse Gas Control*, **27**: 178-87.

Factors affecting salt precipitation

- Formation water composition (+ T, P)
- Residual saturation from viscous displacement
  - Viscosity ratio (breakthrough S_w=0.45 from Koval estimation)
  - Plug orientation
- Injection velocity
  - Uniform precipitation
  - Local precipitation
  - Front-face precipitation



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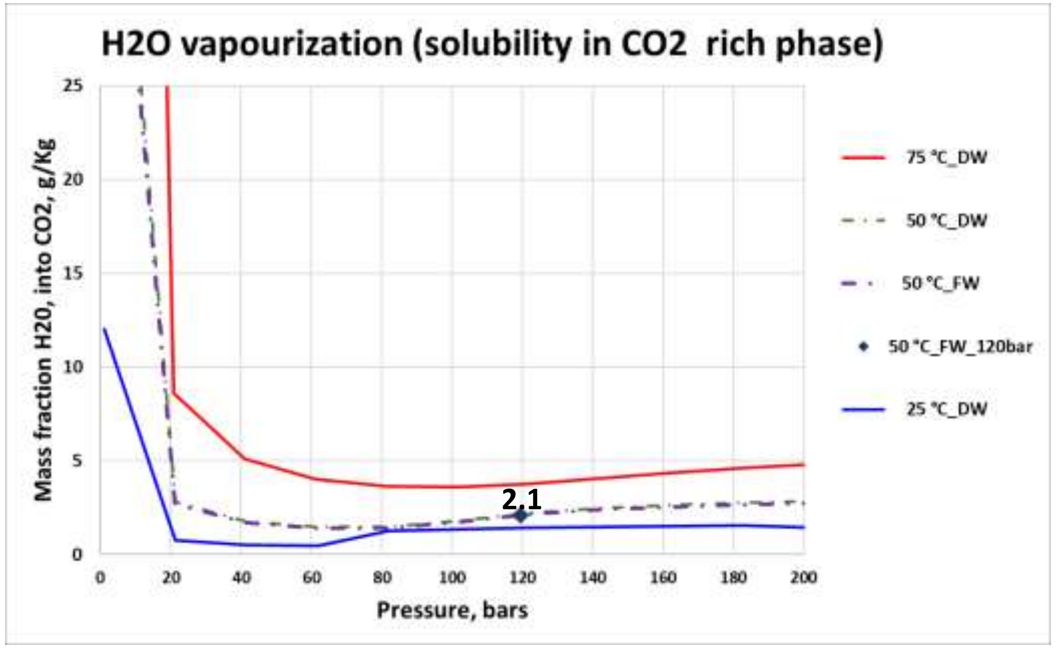
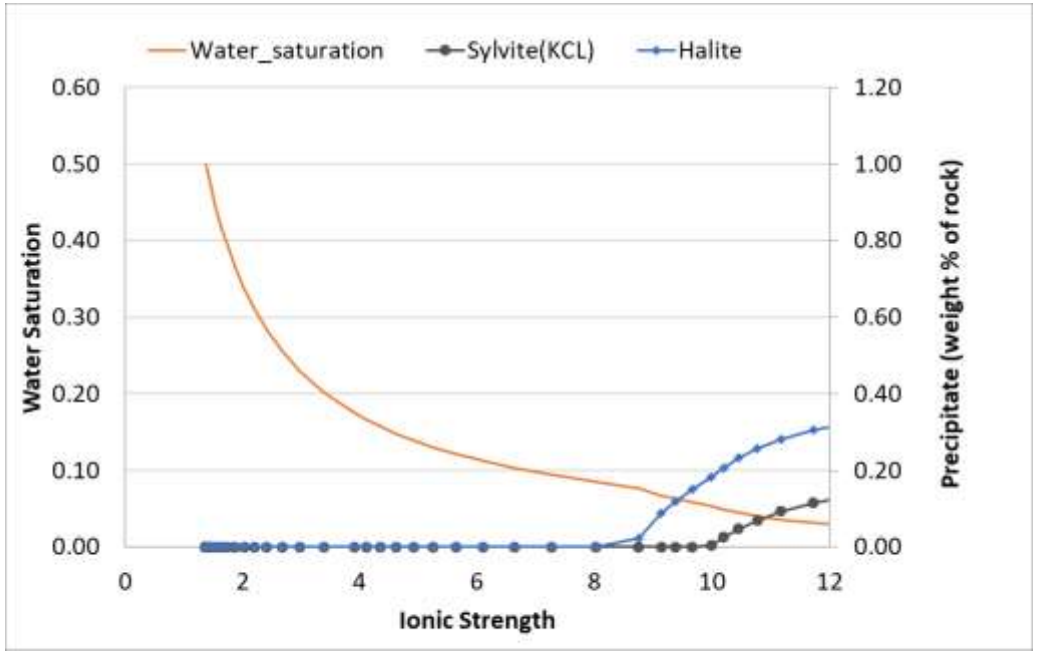
Geochemical simulations PhreeqC

Maximum water content in CO_2 phase



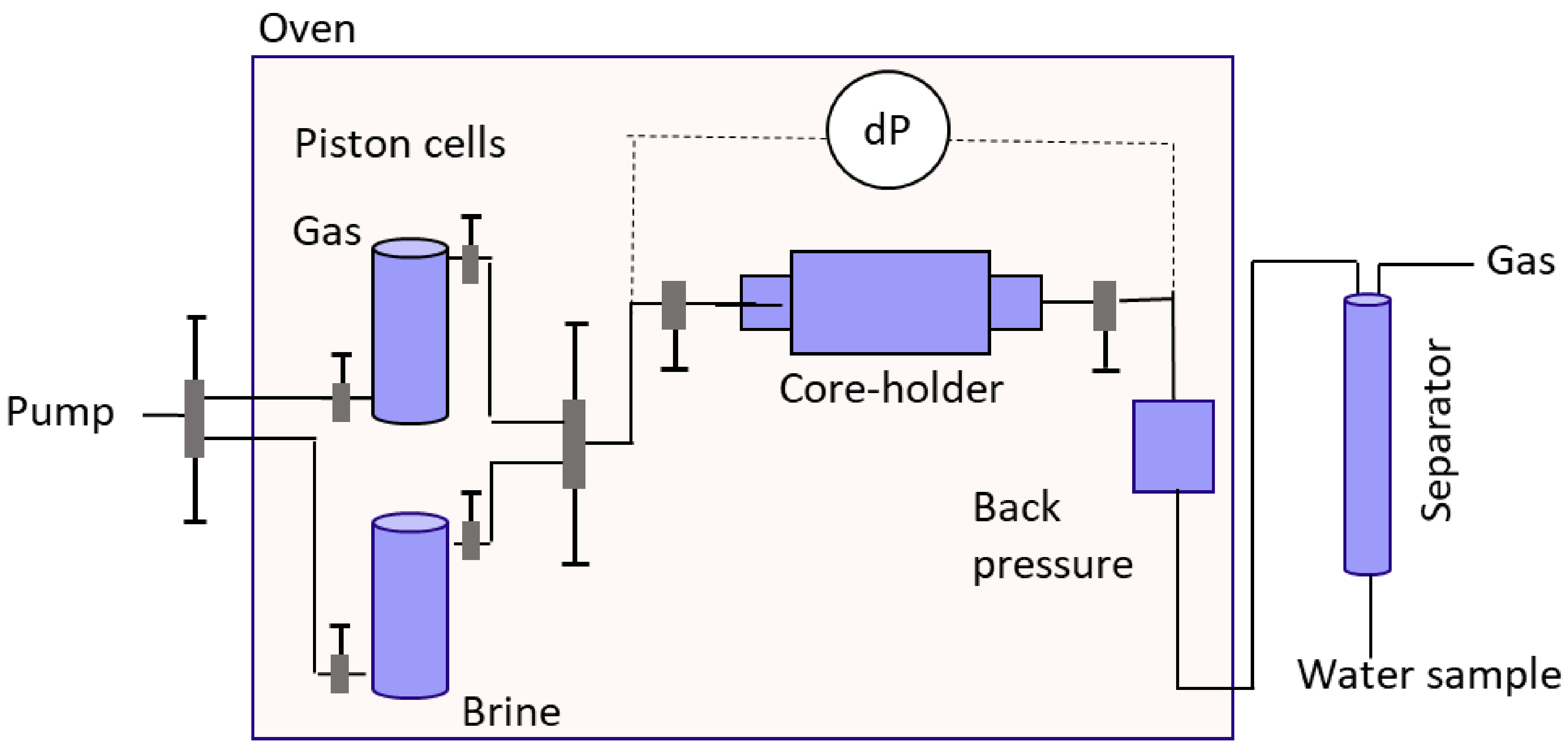
Evaporation of water at test condition



Experiments: Linear Corefloods

- Measure initial CO_2 permeability
- Saturate core with FW and measure initial brine permeability
- Flow CO_2 to displace brine until core is ‘dry’
  - Measure water production
  - Measure differential pressure
- Measure permeability of the dry core
- Analyse cores

Experimental Set-up



All HC steel tubing

Orientation core holder horizontal or vertical

Experiments

- Berea
  - Initial permeability 600 mD and porosity 22%
- Pressure 120 bar
- Temperature 50°C
- CO_2 injection rate
  - 5ml/min =7.2 liters/day

Experiment	Brine		Orientation	Position of separator
1	FW	77K ppm	Horizontal	Room condition
2	High Sal FW	120K ppm	Horizontal	Room condition
3	High Sal FW	120K ppm	Vertical	Room condition
4	High Sal FW	120K ppm	Vertical	Oven after core before back-pressure

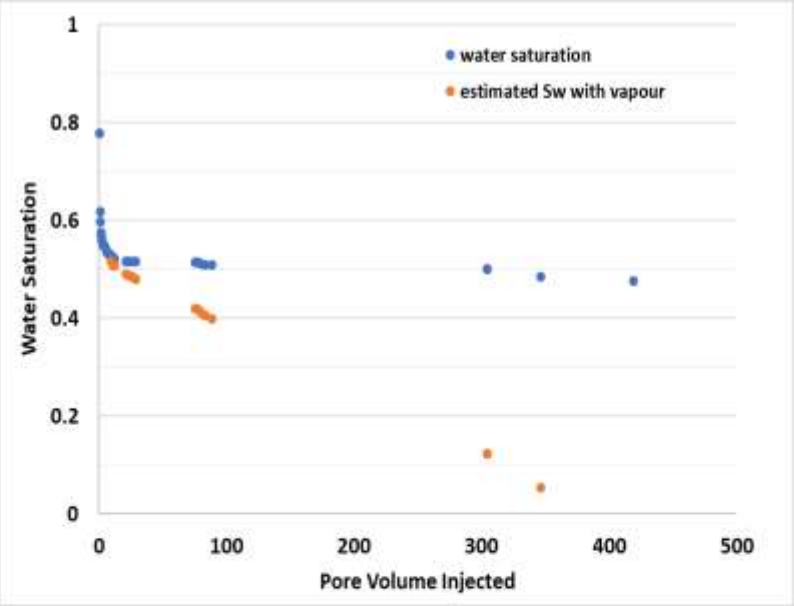
Brine compositions

Ion	FW mg/L	High Salinity FW mg/L
Sodium	23364	**40333***
Potassium	658	658
Calcium	4261	4261
Magnesium	733	733
Barium	483	483
Strontium	382	382
Chloride	46307	**72961***
Bromine	187	187
Lithium	4	4
Total PPM	77 220	120 000

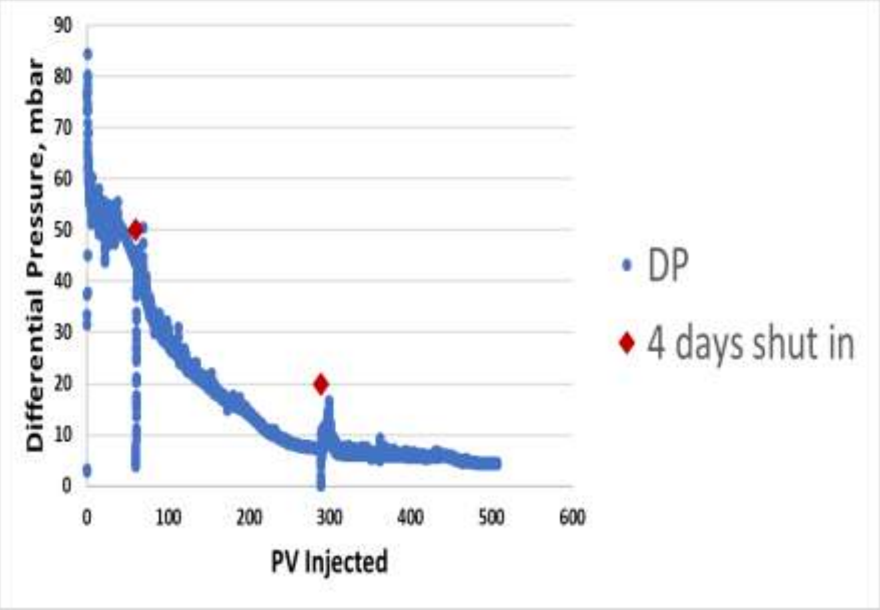
*NaCl added to make brine 120 000ppm

Experiment 1: FW Horizontal

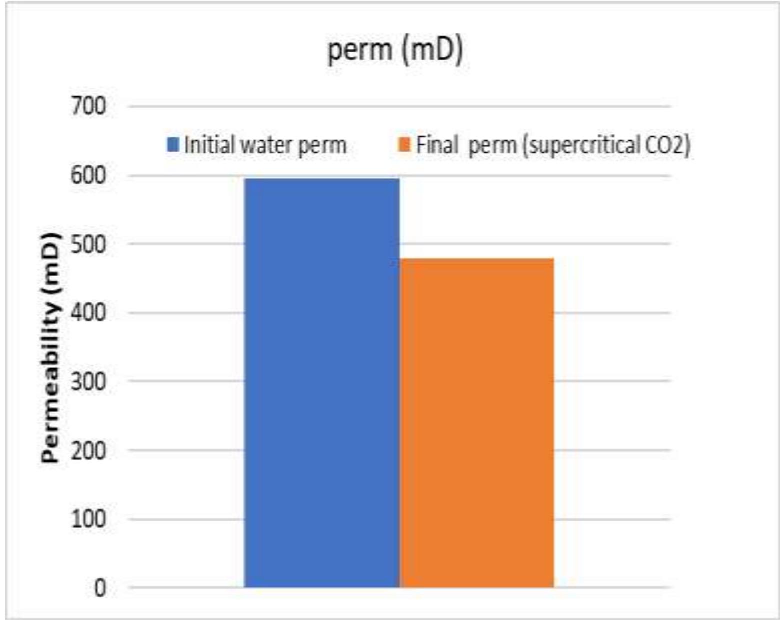
Water Saturation



Differential Pressure profile



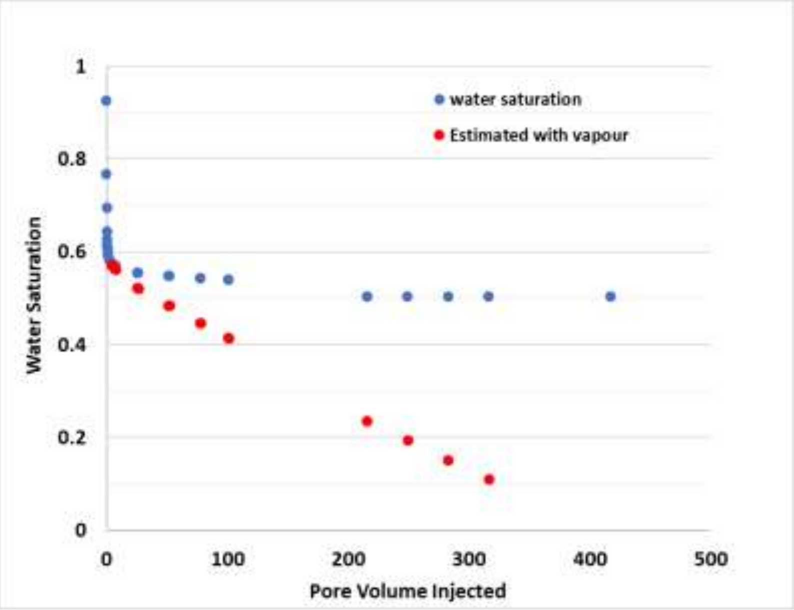
Initial and final perm after drying



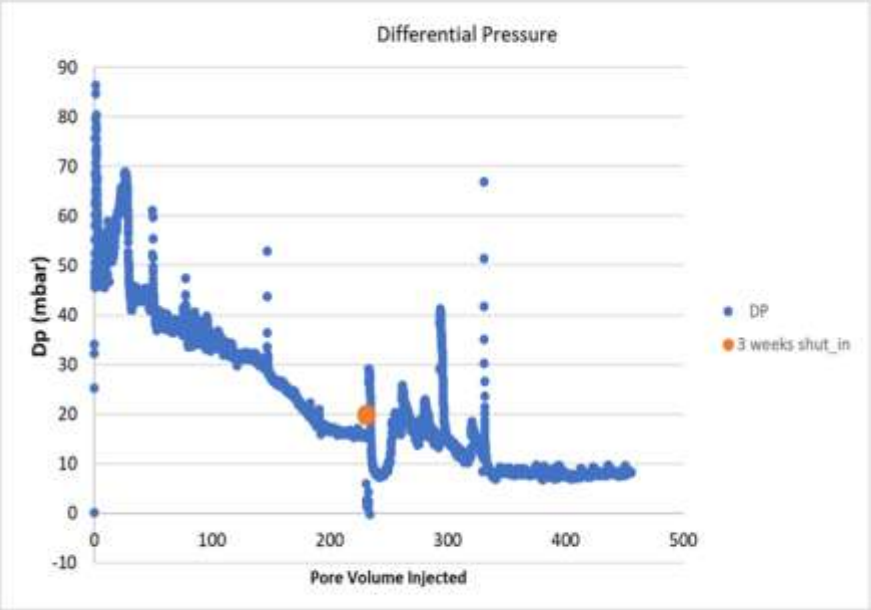
- Water saturation from the liquid phase at the separator
- Water saturation from liquid and vapor (estimated at equilibrium conditions)

Experiment 2: HSFW Horizontal

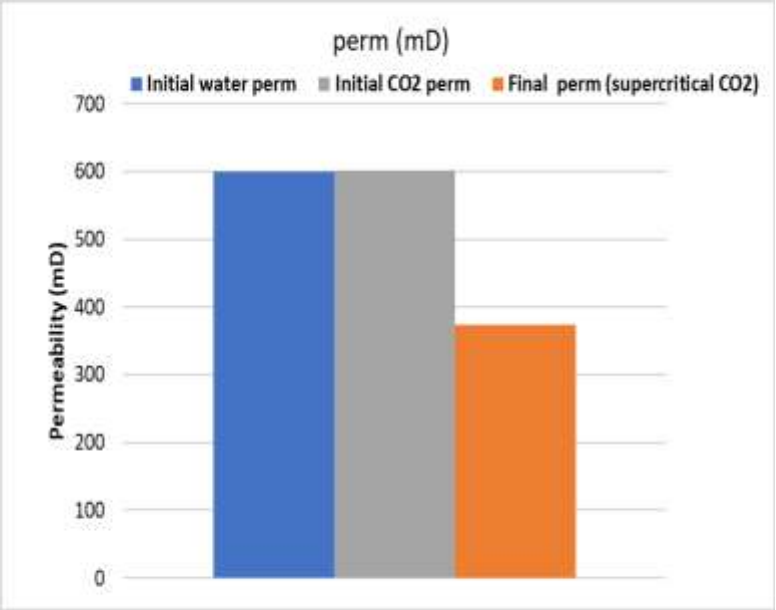
Water Saturation



Differential Pressure profile



Initial and final perm after drying



- Water saturation from the liquid phase at the separator
- Water saturation with estimated (equilibrium conditions) vapour

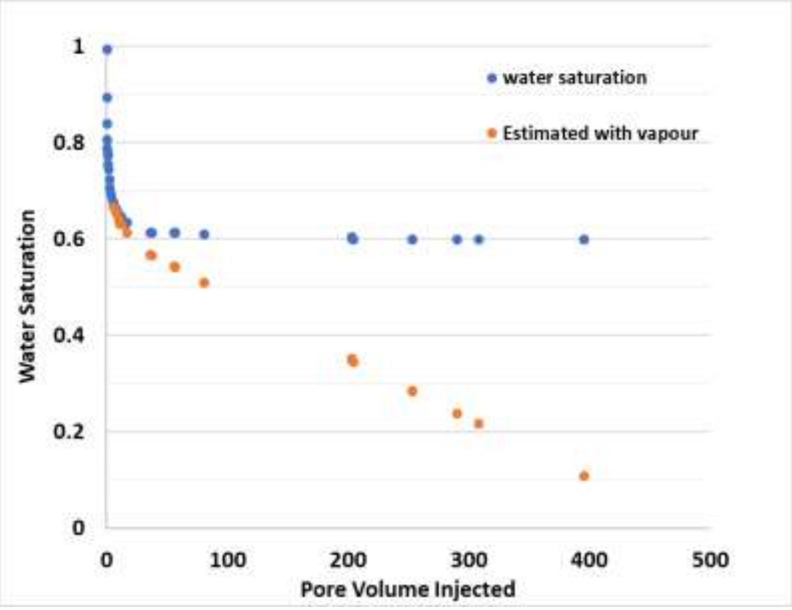
Experiment 2: Core ends

Core Inlet after CO_2 Injection

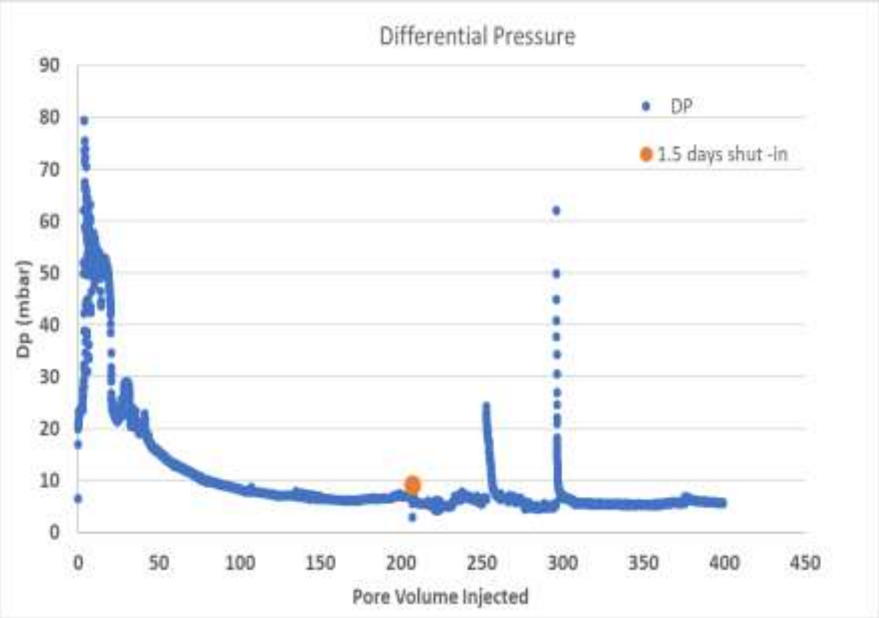
Core Outlet after CO_2 Injection

Experiment 3: HSFW Vertical

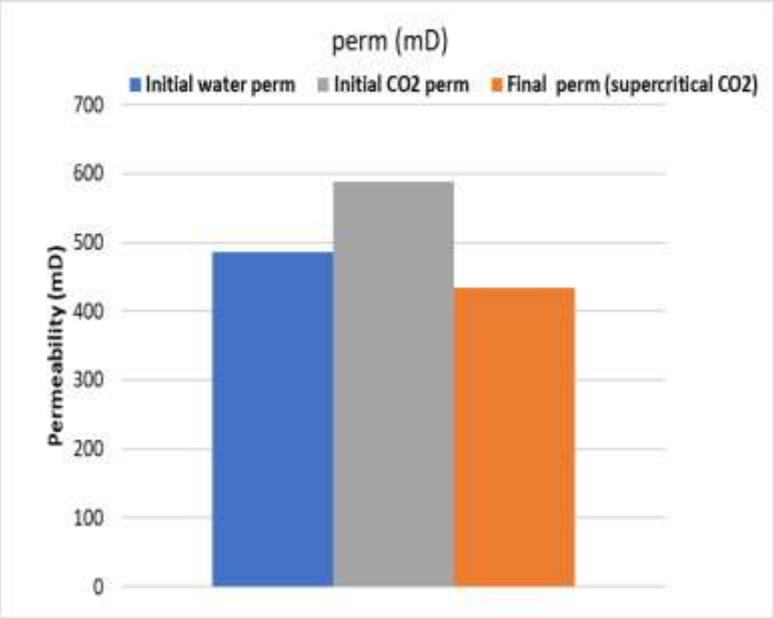
Water Saturation



Differential Pressure profile



Initial and final perm after drying



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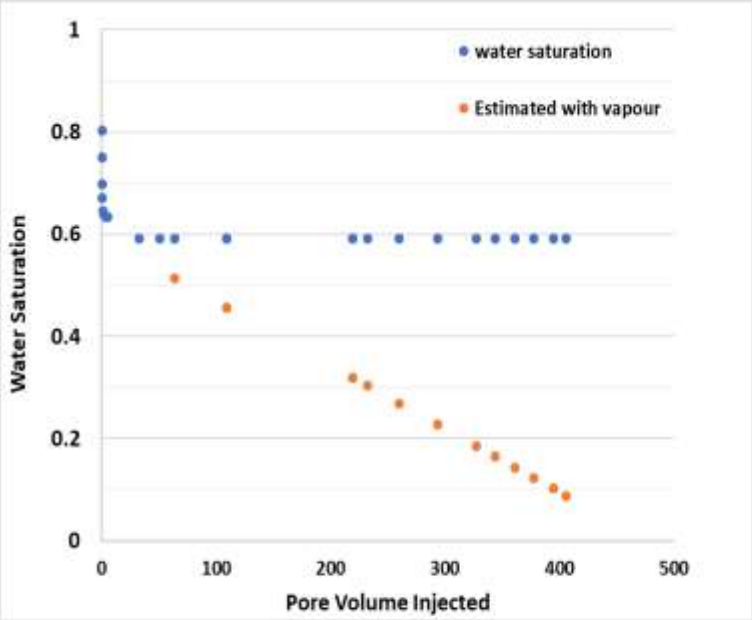
Experiment 3: Core ends

Core Inlet after CO_2 Injection

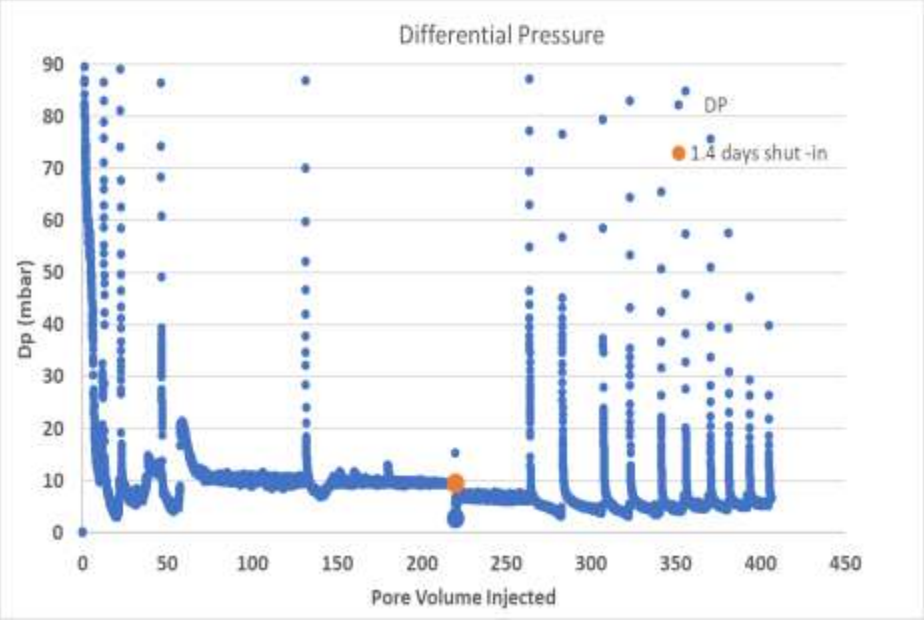
Core Outlet after CO_2 Injection

Experiment 4: HSFW Vertical

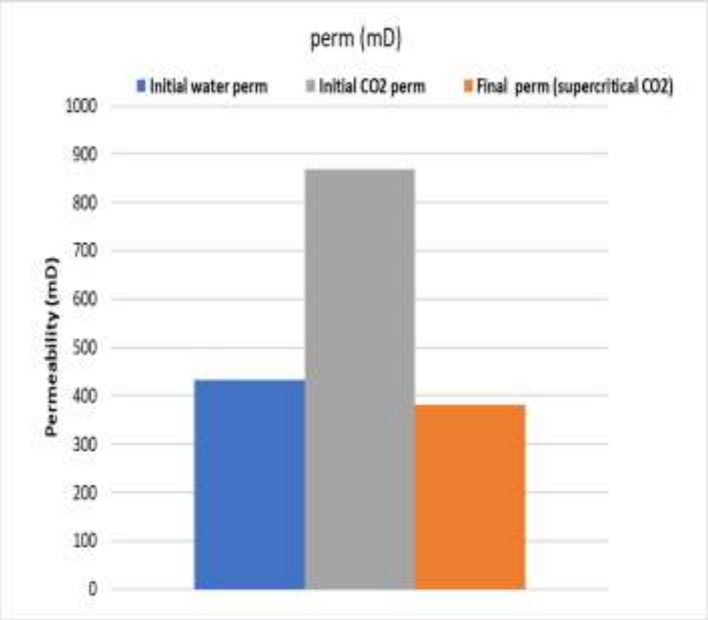
Water Saturation



Differential Pressure profile



Initial and final perm after drying



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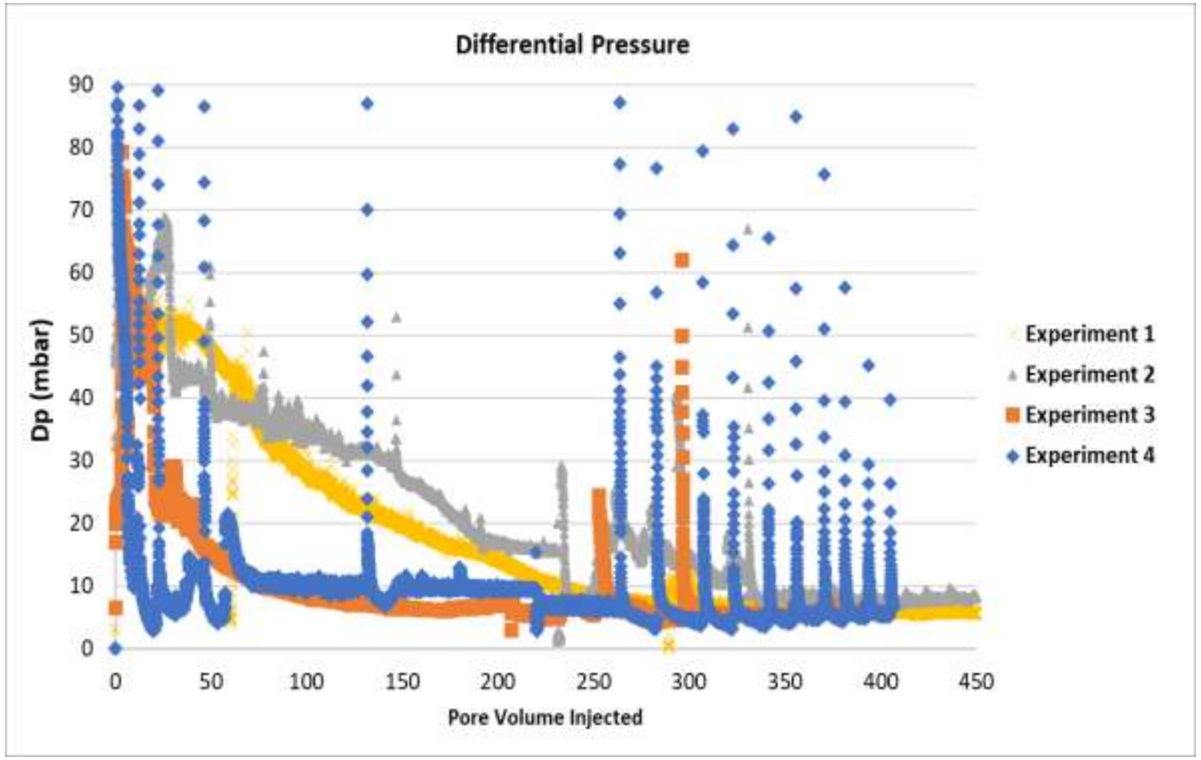
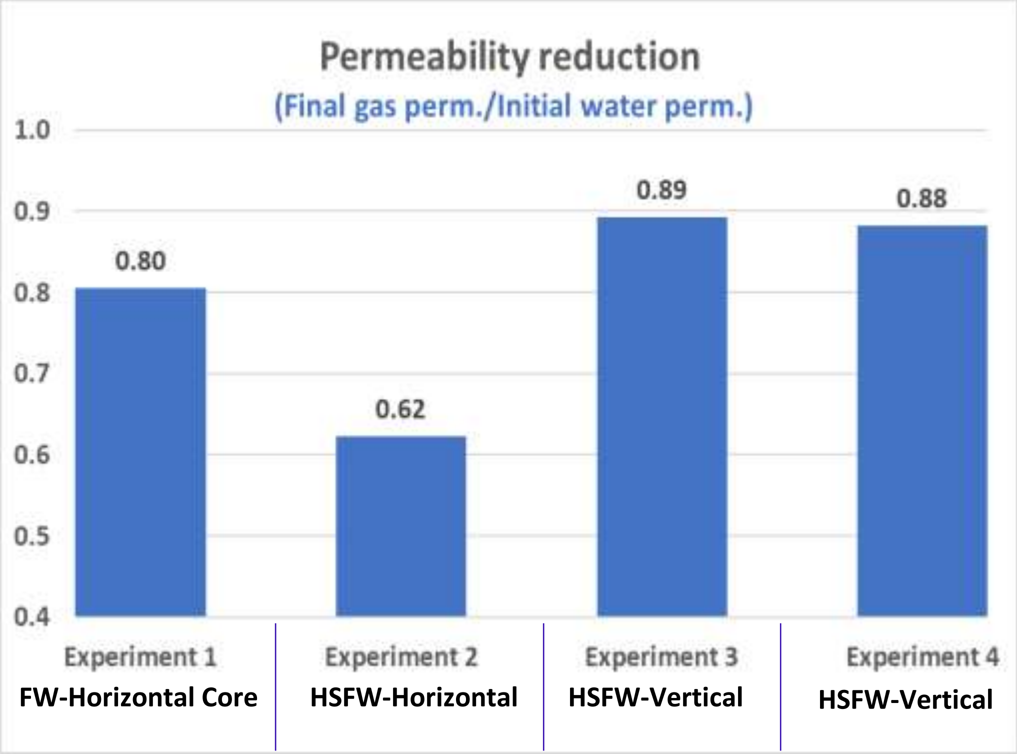
Experiment 4: Core ends

Core Inlet after CO_2 Injection

Core Outlet after CO_2 Injection

Comparison core floods





Experiment	Brine	Orientation	Position of separator
1	FW	Horizontal	Room condition
2	HSFW	Horizontal	Room condition
3	HSFW	Vertical	Room condition
4	HSFW	Vertical	In oven after core

Conclusions

- Permeability reduction observed in coreflood
  - Increases with formation water salinity
  - Depends on orientation, i.e. decreases with increasing displacement efficiency

Future works

- Analysis of the flooded cores
- Study more parameters
- Other rock types

Acknowledgement

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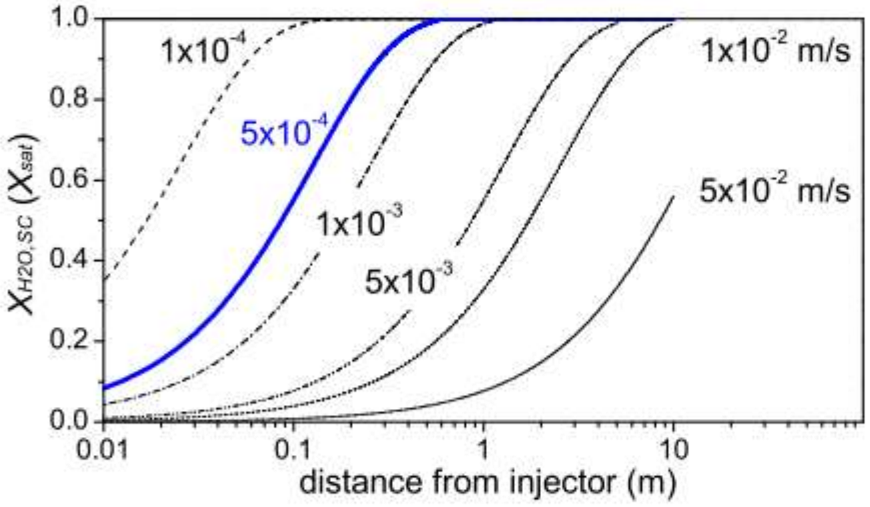
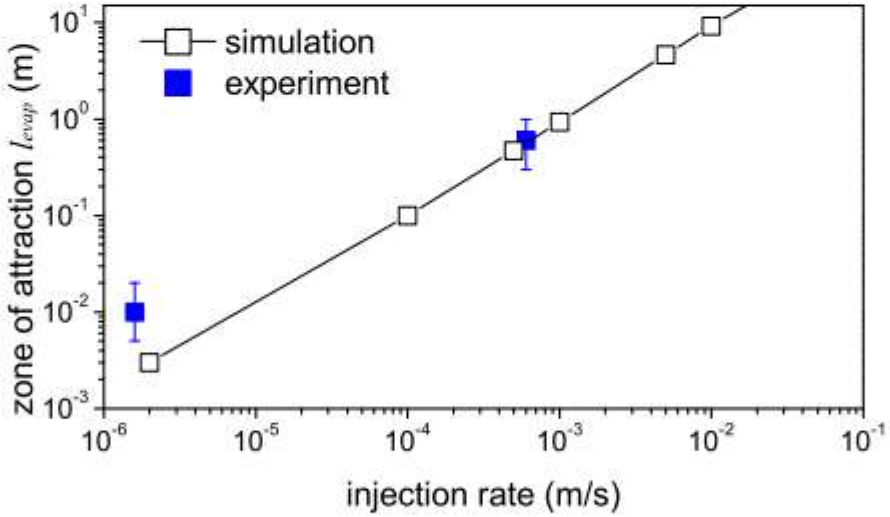
Factors that affect salt precipitation

- Injection velocity
  - Simulations with 45°C and 100 bars
  - 200k ppm salinity
  - 5ml/min =7*10^-5 m/s (darcy velocity) for OUR experiments





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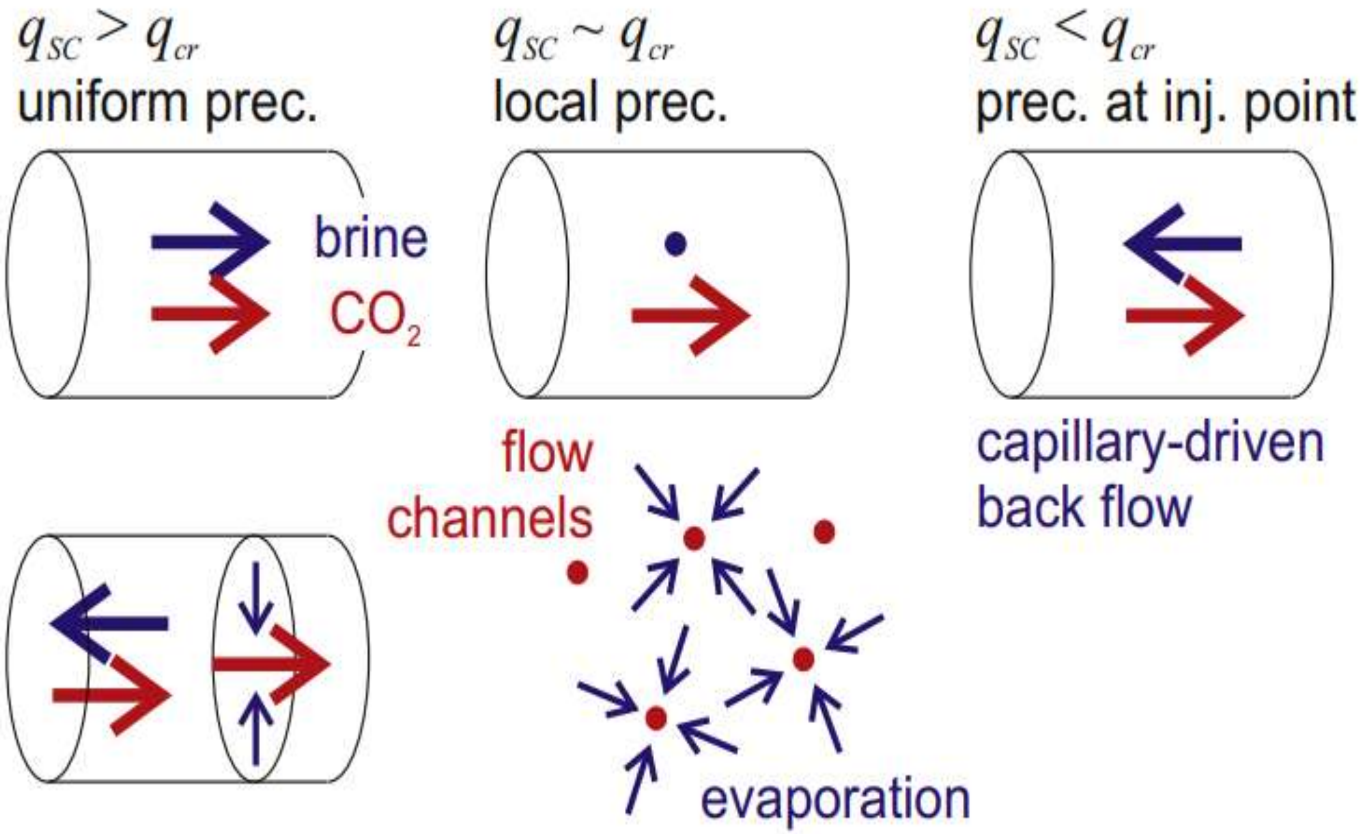
Factors that affect salt precipitation

- Injection velocity

  - Uniform precipitation
  - Local precipitation
  - Front-face precipitation



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