Pore-Scale Insights into In-Situ Mixing Control by Polymer-Enhanced Low Salinity Waterflooding (PELS)

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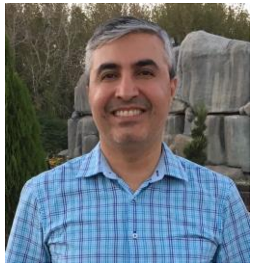
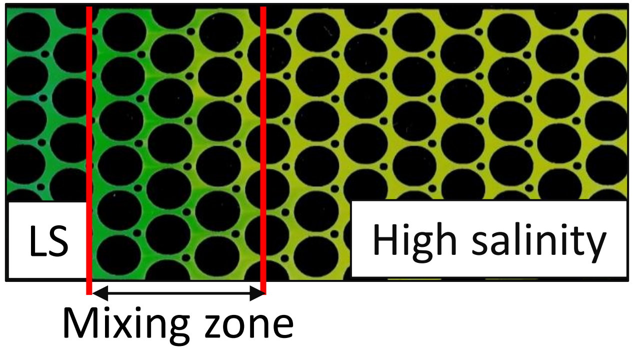
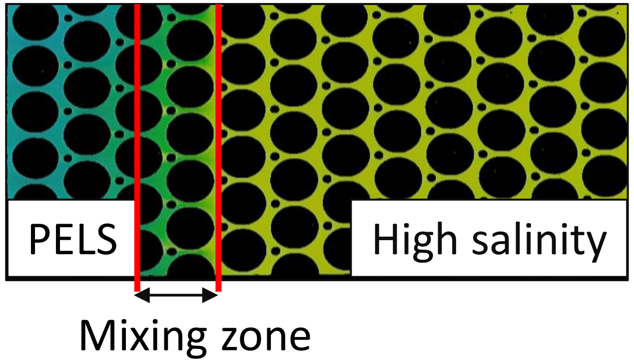


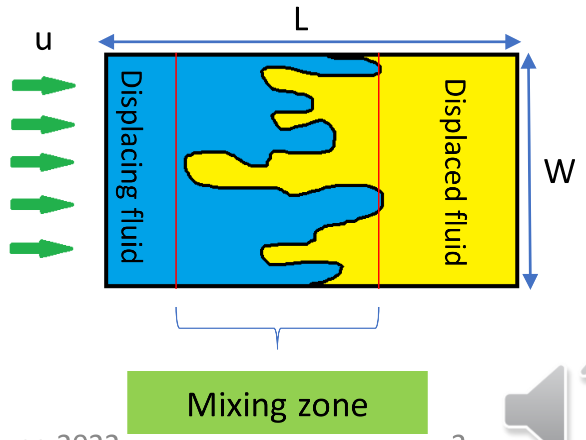




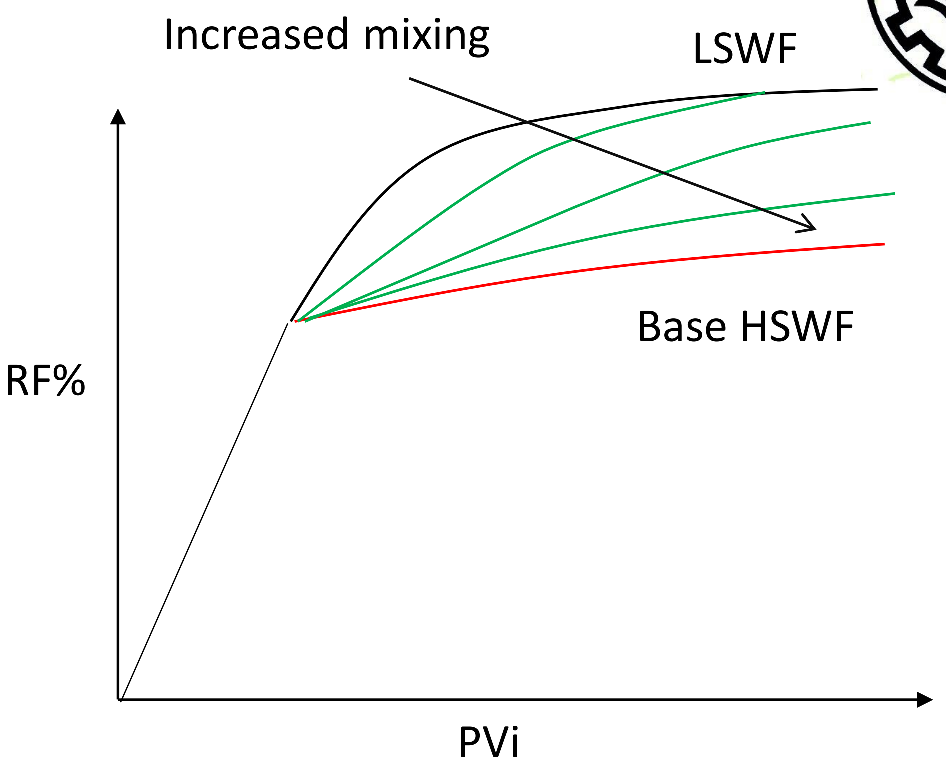
Mahani et al., MS11 Microfluidics and nanofluidics in porous systems, Interpore Society 14th Annual Meeting, 30 May – 2 June 2022

In-situ mixing During Low salinity waterflooding

- Low Salinity Waterflooding
  - Improvement of microscopic sweep via modification of brine composition
  - Acceleration of oil recovery, delay of BT time, reduction of water-cut
- Prerequisite for Low Salinity Effect:
  - Establishment of LS conditions in individual pores to trigger the necessary solid-liquid and liquid-liquid interactions
  - Difficult in stagnant zones, easier in flow zones
- Challenge: in-situ mixing between the resident HS and injection LS
- Origin of mixing:
  - Dispersive transport of salt and viscous fingering at LS and HS front
  - Rate of growth of mixing zone length $L \propto (\sqrt{t})$ to (t)



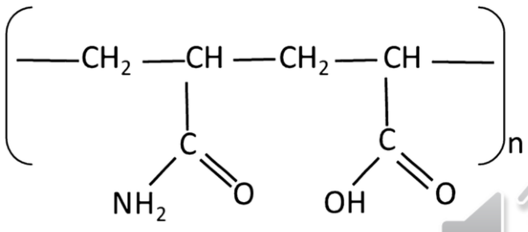
Proposed solution



- Negative economic consequences
  - Part of low salinity volume becomes ineffective
  - Delay in wettability alteration and oil production
  - Increased injection PV of LSWF → NPV↓
- Proposed solution to tackle mixing
  - Develop a hybrid method
  - Viscosify the LS stream by adding a small amount of HPAM polymer → polymer enhanced low salinity flooding (PELS)
  - Improvement of viscosity (mobility) ratio at brine-brine (miscible) front

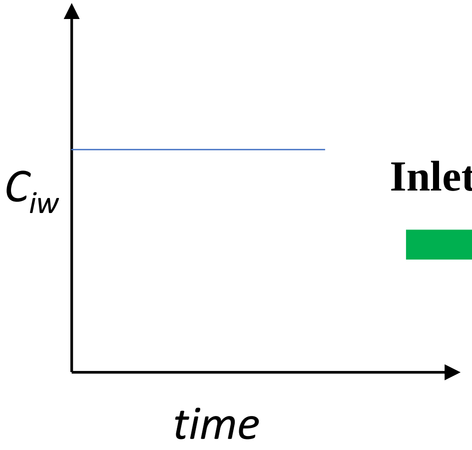
$$M_{brine=brine}\downarrow$$

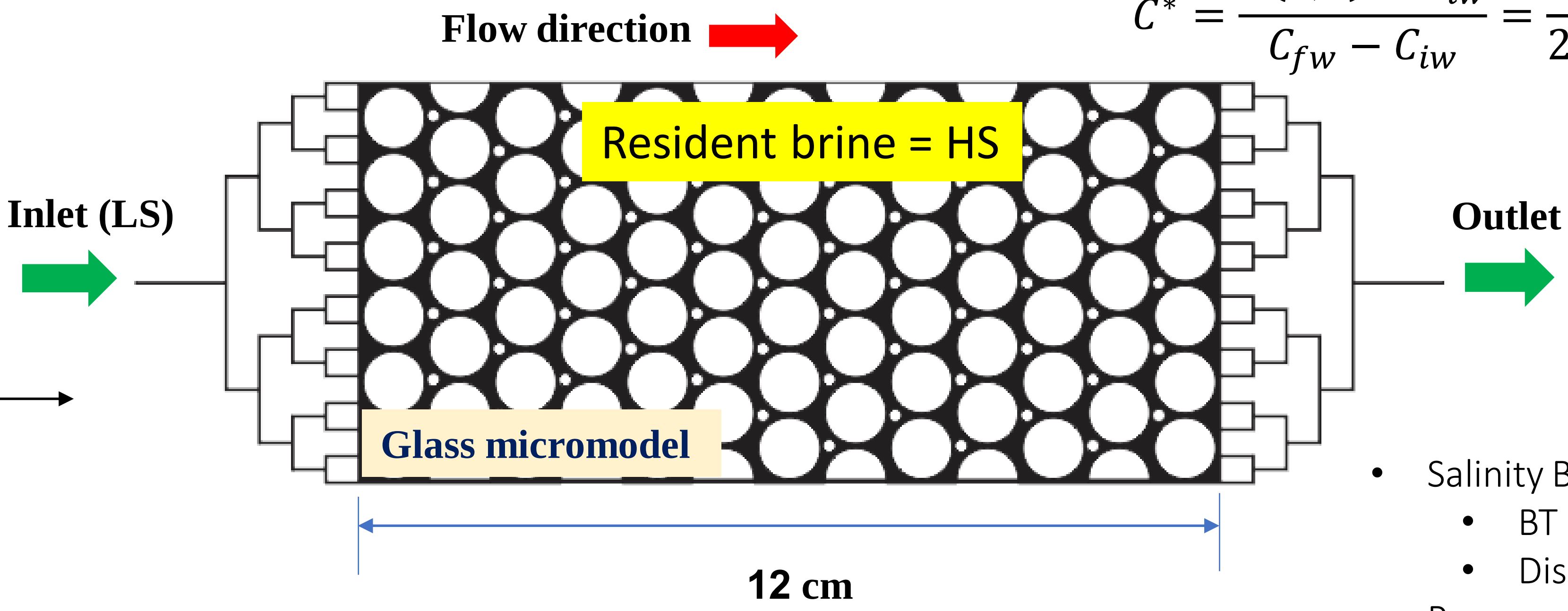
HPAM

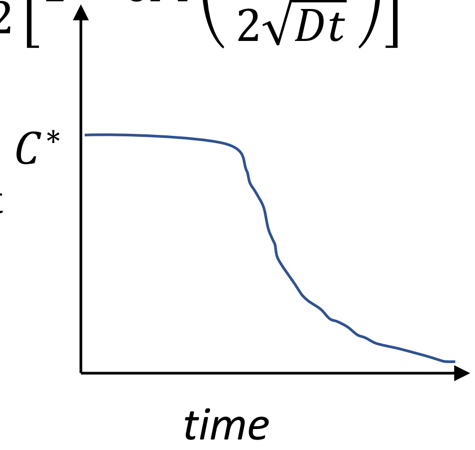


Microfluidics mixing experiments & modeling based on adv.-disp. theory

$$C^* = \frac{C(x,t) - C_{iw}}{C_{fw} - C_{iw}} = \frac{1}{2}\left[1 - \mathrm{erf}\left(\frac{x - vt}{2\sqrt{Dt}}\right)\right]$$





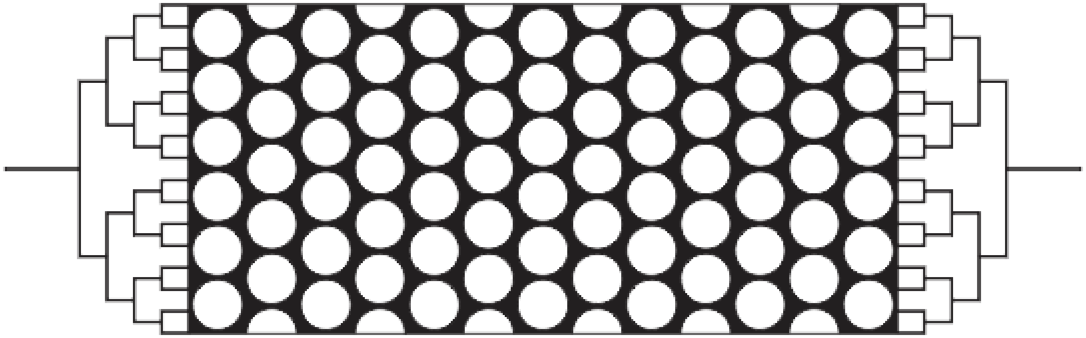


- Salinity BT curves
  - BT time
  - Dispersion coefficient
- Pore-scale calculations:
  - Location of salinity front
  - Length of viscous fingers
  - Length of mixing zone (ΔX)

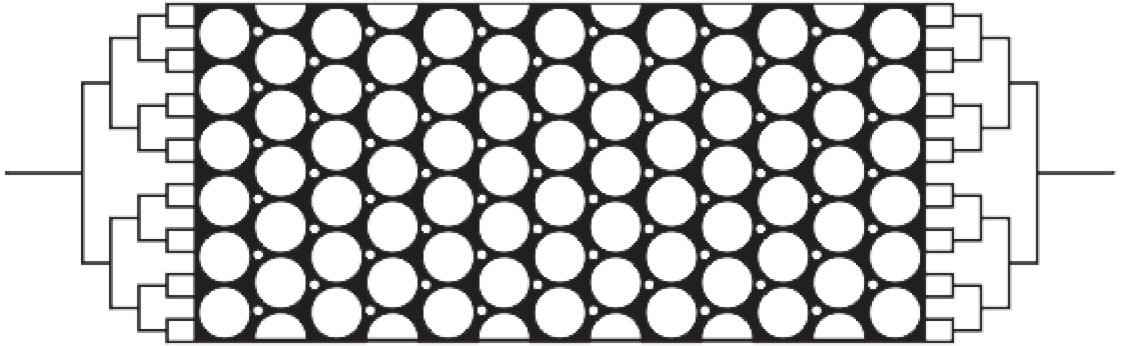
- Effect of HPAM polymer concentration (0, 250, 500, 750 ppm)
- Effect of Displacement velocity (6 - 12 ft/day)
- Degree of heterogeneity

$$\Delta X = X_{U_H} - X_{U_L} = 4 \times erf^{-1}(1 - 2U_L)\sqrt{\frac{T}{N_{Pe}}}$$

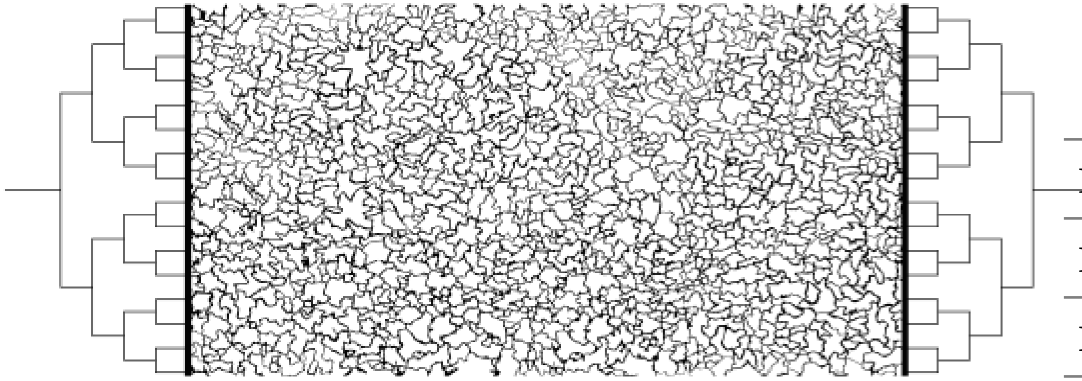
Three designs of microfluidic device



• **Homogeneous model 1**



• **Homogeneous model 2**



• **Heterogeneous model**

Pattern	Pore Radius (µm)	Pore Throat (µm)	Pore Depth (µm)	Physical Dimensions (mm)	Pore Volume (cm3)	Porosity (%)
Homogeneous 1	650-800	550	115	448×146	0.175	42.8
Homogeneous 2	650-750	450	115	448×146	0.162	39.4
Heterogeneous	250-450	150-200	105	702×196	0.421	32.8

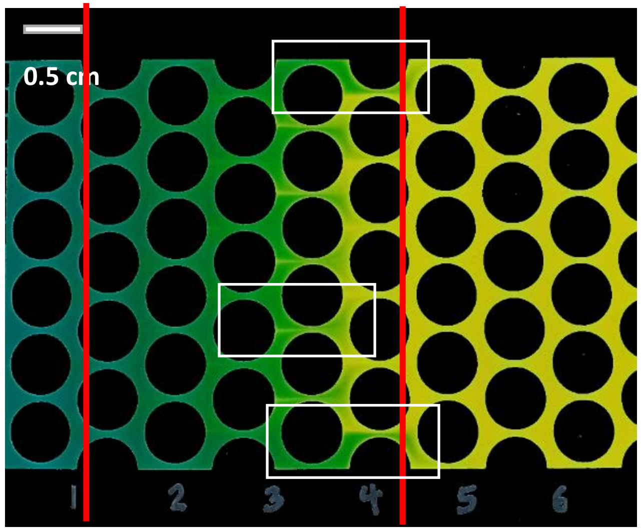
Mixing results for homogeneous model 1

LS/PELS dyed blue
HS dyed yellow
Mixing zone: Green area
Vertical red lines: mixing zone

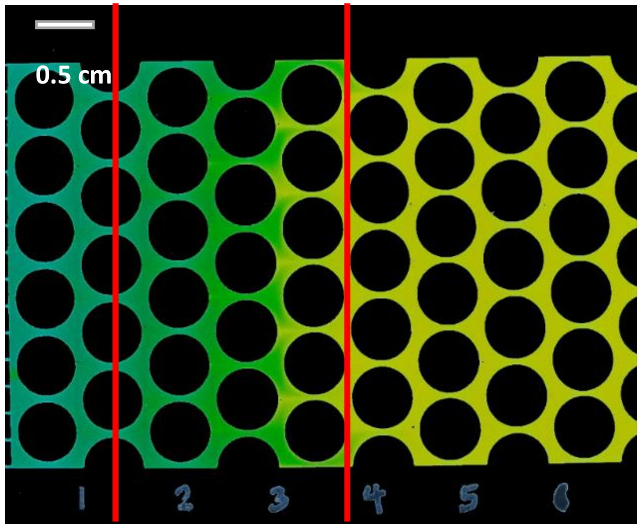
Flow direction

Injection rate = 0.5 cc/hr

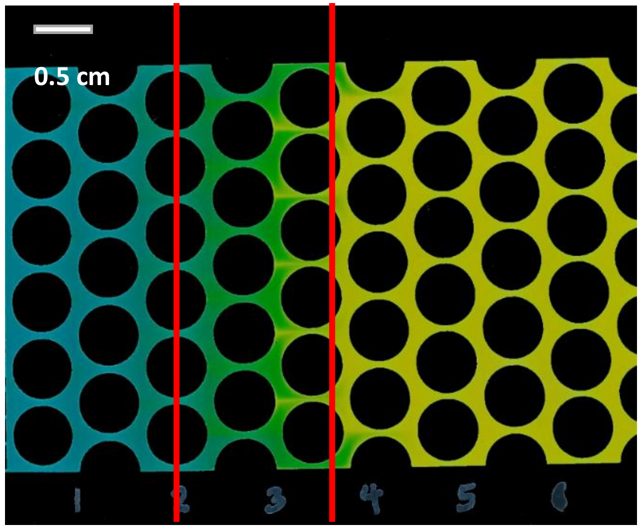
Images after: 0.5 PV injection



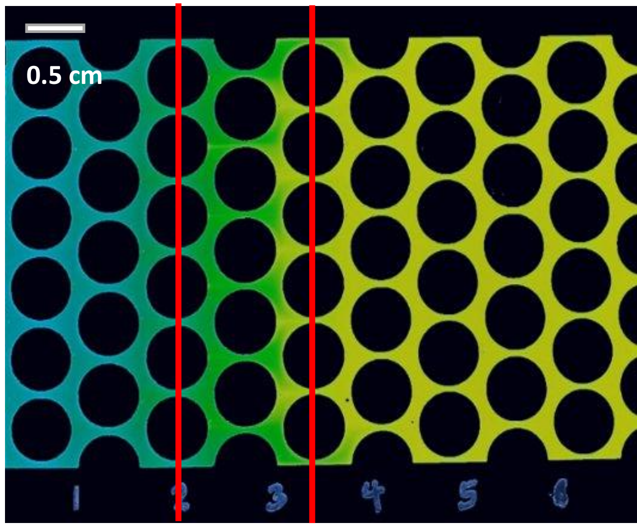
- LS: No Polymer
- Extensive mixing behind front
- Salinity fingers observed (~ 0.75 cm)
- ~ Linear growth of fingers with time



- PELS: 250 PPM

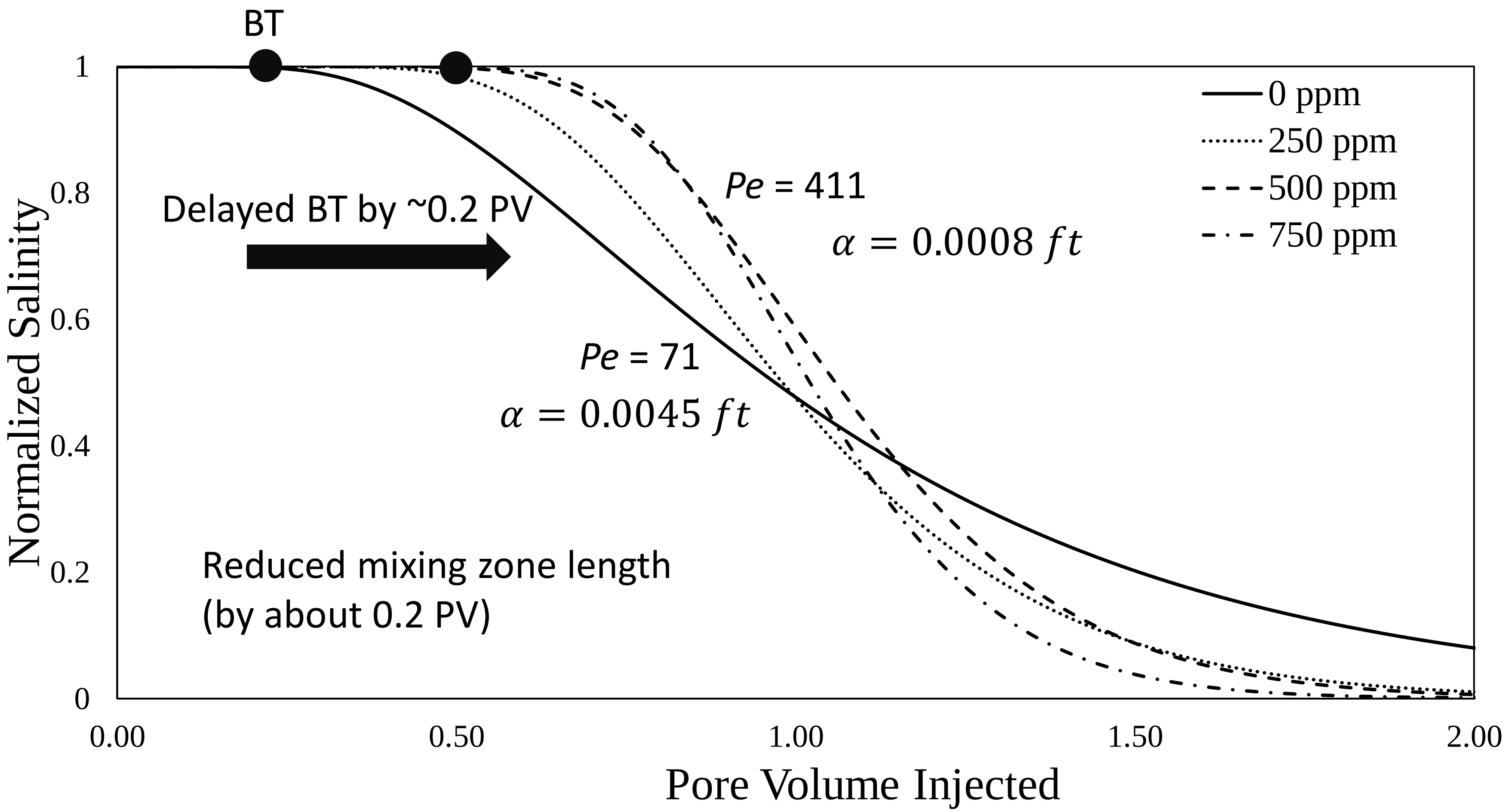


- PELS: 500 PPM



- PELS: 750 PPM
- Significant reduction of mixing zone

Impact of HPAM concentration on salinity breakthrough curves in homogeneous model 1



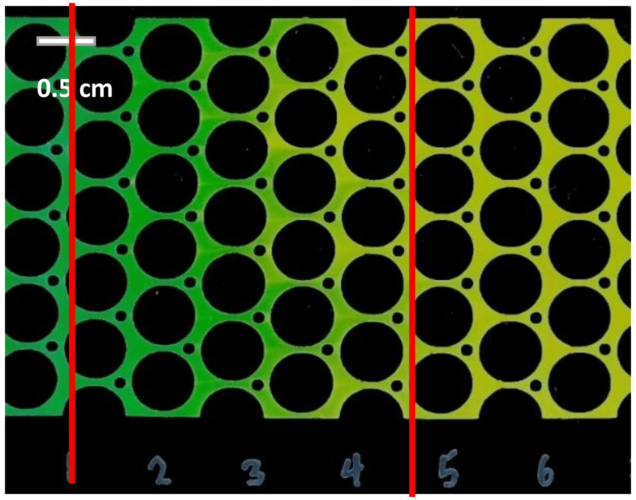
Mixing results for homogeneous model 2

Flow direction

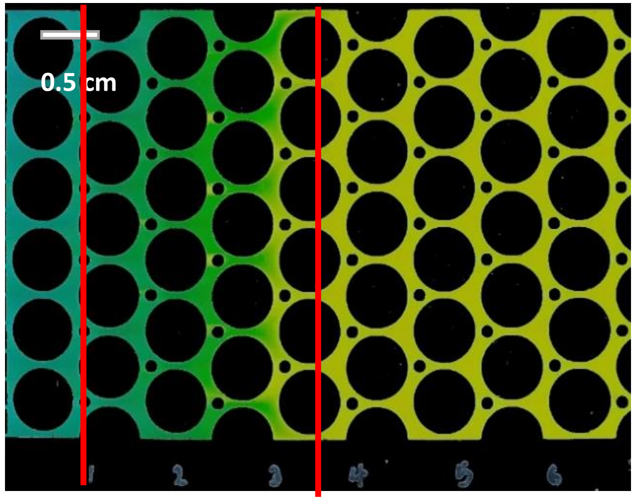
LS/PELS dyed blue
HS dyed yellow
Mixing zone: Green area
Vertical red lines: mixing zone

Injection rate = 0.5 cc/hr

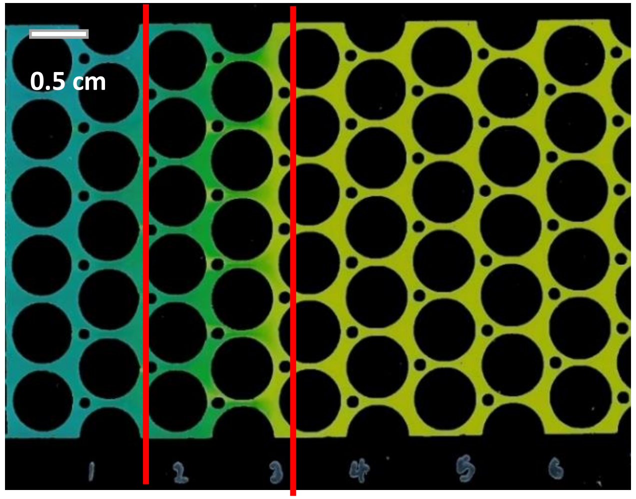
Images after: 0.5 PV injection



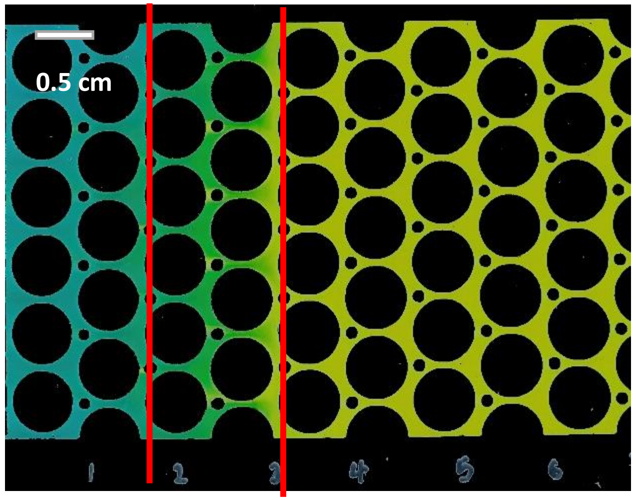
- LS: No Polymer
- Extensive mixing behind front
- Intensified mixing compared to model 1



- PELS: 250 PPM



- PELS: 500 PPM



- PELS: 750 PPM
- Significant reduction of mixing zone

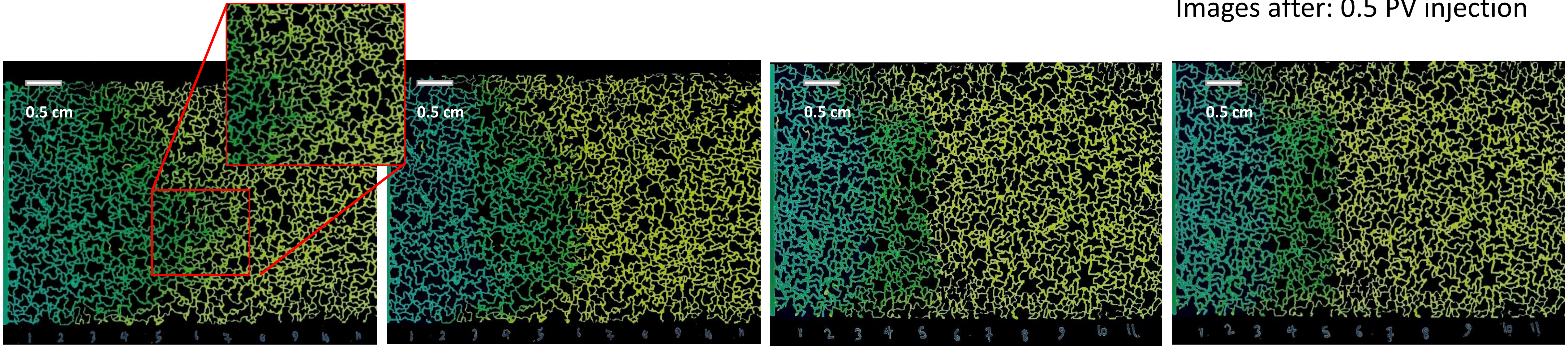
Mixing results for heterogenous model

LS/PELS dyed blue
HS dyed yellow
Mixing zone: Green area

Injection rate = 0.5 cc/hr

Images after: 0.5 PV injection

Flow direction



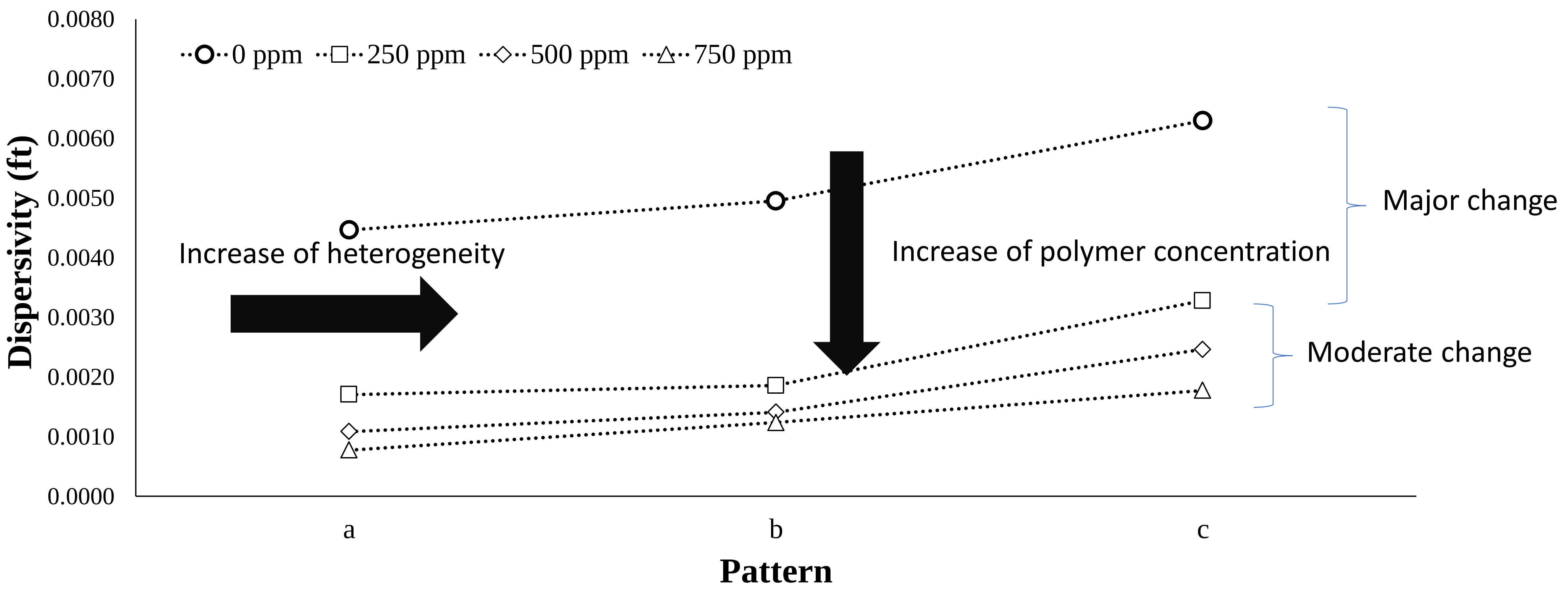
- LS: No Polymer
- Extensive mixing behind front
- Very non-uniform salinity transport
- Intensified mixing compared to models 1 & 2

- PELS: 250 PPM

- PELS: 500 PPM

- PELS: 750 PPM
- More uniform salinity transport
- Significant reduction of mixing zone

Impact of heterogeneity on dispersivity at different polymer concentrations



Summary of key points

- Non-uniform salinity transport and generation of LS salinity fingers in HS because of unfavorable viscosity ratio between LS and HS
- Rate of growth of salinity fingers (almost) proportional to time in absence of polymer
- Increasing the complexity of flow pattern & degree of heterogeneity increases the dispersivity.
- Adding 250 ppm HPAM reduced the salt dispersivity by 62% in homogeneous models – consistent with our recent core-scale experiments.
- **Working mechanism of PELS:** increased stability of brine-brine interface and sharpening of displacement front via reduction of the viscosity ratio between brines
- Delayed breakthrough of LS by 0.08 – 0.2 PV for homogeneous models, for heterogeneous model between 0.03 – 0.09 depending on polymer concentration
- Reduction of mixing zone length by ~ 0.2 occupied PV, thus a lower injection volume of LS would be required.

Thank you for your attention

Check also:

MS08: Talk ID#274

How does the presence of an oil phase influence the non-Fickian salt transport during low salinity waterflooding EOR?

Speaker: Arman Darvish Sarvestani

Tuesday 31 May