Flowing foam reinforced with polymer or particles : application to LNAPL pumping for soil remediation

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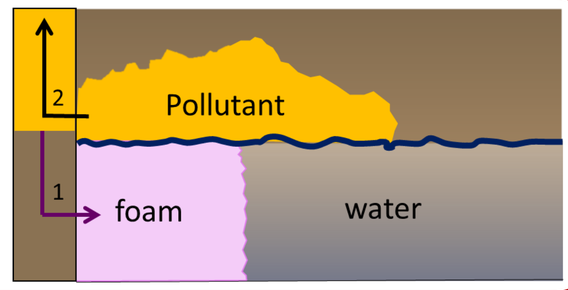
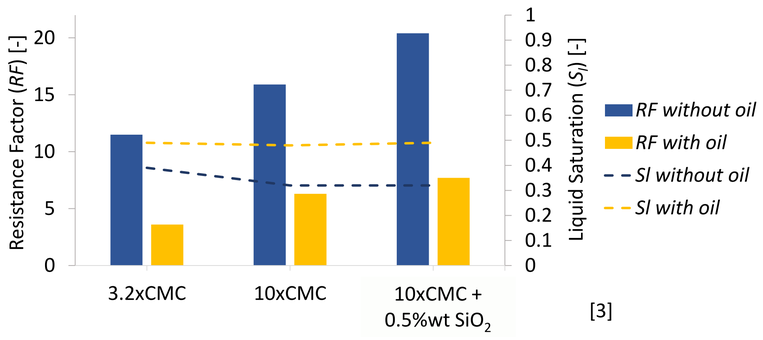
Context & Objectives

To prevent aquifers pollution due to industrial leak and to remediate soil pollution, liquid foams can be used [1]. However, in the presence of oil, foam collapses and its life time is reduced [2]. Previous results in sandpack experiments proved the importance of surfactant concentration and particles addition to reinforce foam against oil-induced destruction. So, to understand of foam will be impacted by gravity during remediation, the behavior of foam flowing in a vertical 2D porous media is now investigated. Foam front and physical observations, as well as liquid and gas phases displacement help to reach this objective. Then, foam resistance against oil is investigated in the presence of a top layer at residual oil saturation to simulate the interface between an aquifer and a spread oil.



Previous results in sandpacks

Foam co-injection in sandpack columns:

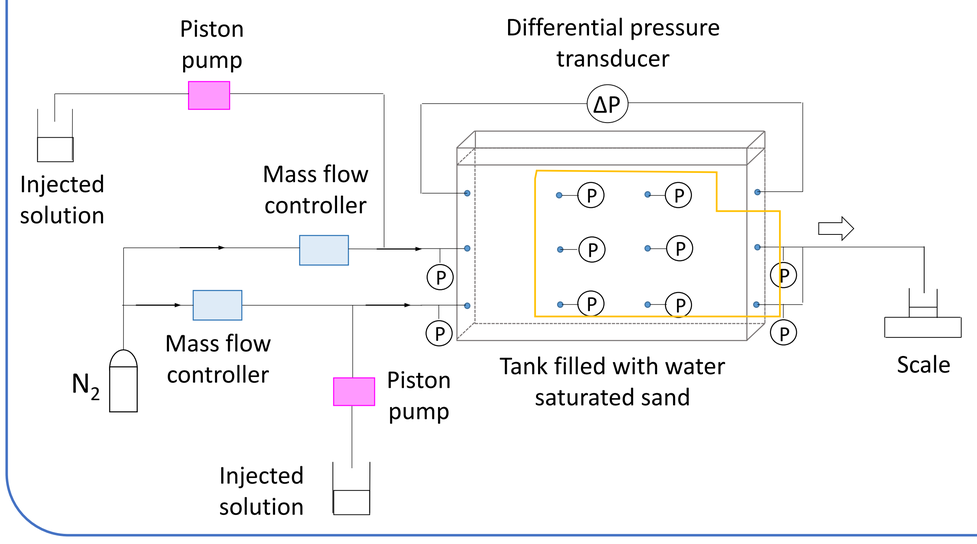


[3]

- Importance of surfactant concentration
- Foam degradation by oil
- Foam is reinforced by particles addition

Materials & Methods

Set-up for 2D-tank experiments:



Foam formulation:

- Surfactant: Saponin = plant-based
- Particles: Silica particles SiO_2
  - ✓ Biodegradable and/or non-toxic products

Objectives for foam properties:

- Good sweeping efficiency given by low S_w
- High blocking ability with high lamella density, obtained with high pressure
- Biodegradable and non-toxic foam

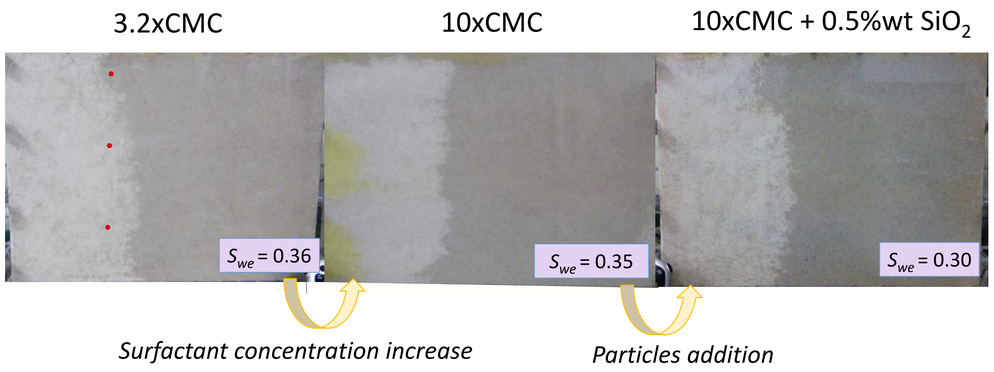
Key parameters:

- Water saturation at equilibrium $S_{we} = \frac{V_{water\ at\ equilibrium}}{pore\ volume}$
- Pressure

Results

In the absence of oil

Foam co-injection experiments:



Observations

- Piston-like front
- Same constant velocity front
- Decrease in S_w with particles
  ⇨ Better sweeping efficiency

Aqueous and gas phases behavior:

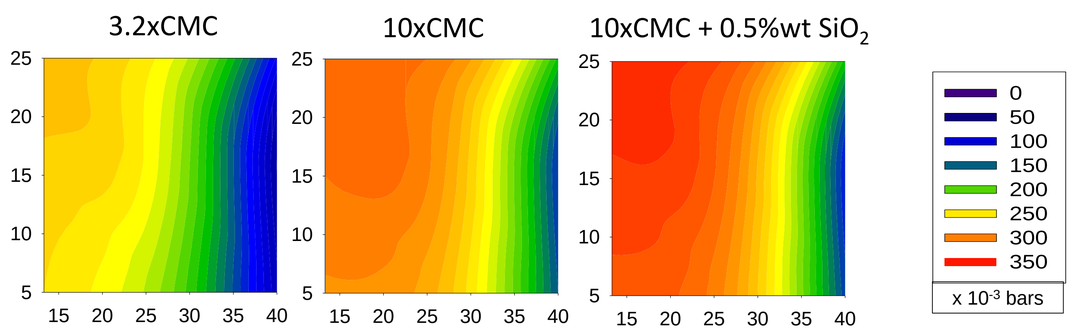
Dyed aqueous phase of 10xCMC solution

- Strong gravity impact on liquid phase
  ⇨ Foam quality gradient on the full height

Gas injection alone in a 10xCMC surfactant saturated medium

- No noticeable gravity impact on gas phase implying foam formation
  ⇨ Necessity to saturate the medium before injecting foam

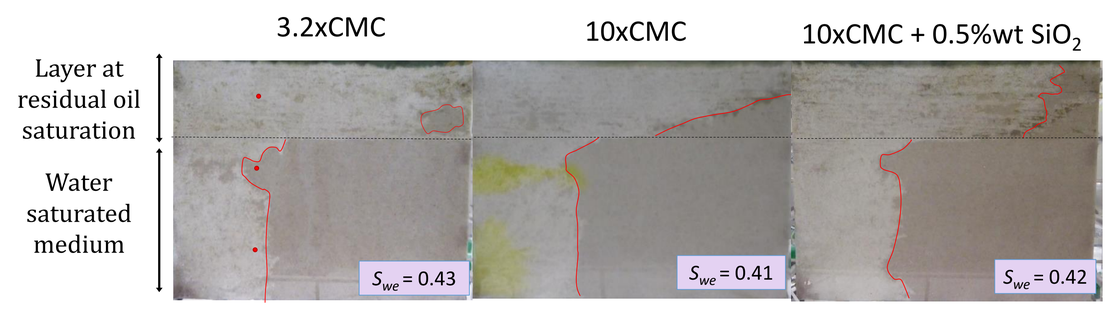
Pressure map at equilibrium:



- Vertical pressure distribution
- Pressure increases with surfactant concentration increase and/or particles addition

In the presence of oil

Foam co-injection experiments in the presence of oil:



Observations

- Two different front behaviors
- Increase surfactant concentration & particles addition
  ⇨ straighter fronts

Hypothetical foam propagation mechanism

1. Foam starts propagating,
2. Reaches the top layer
3. Gets partly destroyed by oil
4. Creates a preferential path for weak foam

Meanwhile at the bottom:
1 -> 4 Foam keeps on propagating

Measured propagation velocity:

Velocity Ratio: $V_r = \frac{v_{top\ layer}}{v_{bottom\ layer}}$

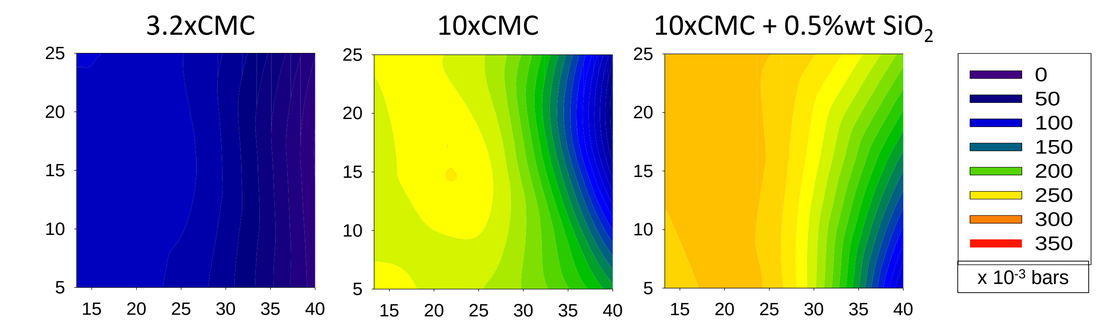
Formulation	3.2×CMC	10×CMC	10×CMC + 0.5%wt SiO_2
Vr	4.03	2.74	2.59

Observations

- Increase surfactant concentration
  ⇨ Decrease in velocity ratio
- Particles addition
  ⇨ Decrease in velocity ratio and straight front

Foam reinforcement

Pressure map at equilibrium:



- Vertical pressure distribution despite partial oil destruction
- Stronger oil resistance with concentration increase and/or particles addition

Conclusions & Perspectives

This foam-injection technique based on the use of biodegradable surfactants, shows promising results, and a few lessons are to be highlighted for soil remediation purpose. First, preliminary tests in porous medium are necessary to obtain the right foam formulation, strong enough to cope with partial oil induced destruction. Then, to obtain a strong foam from the beginning of the process, it appears necessary to inject a few pore volume of surfactant solution before foam injection. Furthermore, foam shows interesting blocking properties, both in a water saturated area, and in the presence of oil at residual saturation, which is in particular reflected by vertically distributed pressures. Conclusions drawn by those experiments can be useful to represent foam behavior at the interface between the aquifer and the oil spread, where oil is present at residual saturation. Following this study, foam injection is to be tested in 3D pilot followed by oil pumping to validate the method. Simulations and field experiments could then be considered.

Bibliography

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