Stability assessment of foam enhanced by surfactant, polymer and nanoparticles in the presence of petroleum hydrocarbons

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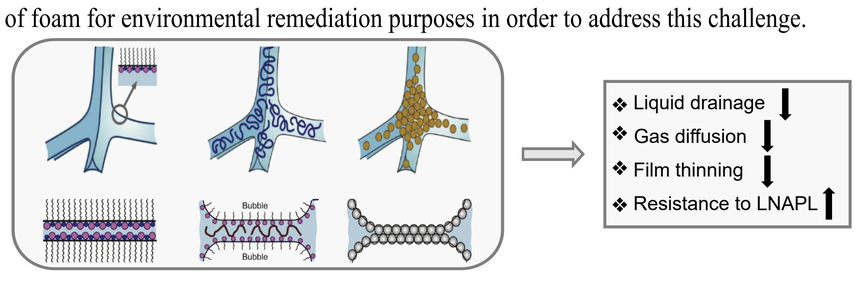
1 Introduction and objectives

Light Non-Aqueous Phase Liquids (LNAPLs) pose significant **environmental and health risks** and can be challenging to remediate. **Pump-and-treat** method's efficiency rarely exceed **60%** due to the **heterogeneity** of the subsurface [1].

The use of aqueous foam in environmental remediation has already proven to be a promising technique for **in situ remediation of NAPLs** [2].

However, **contact with petroleum compounds** tends to significantly **deteriorate the stability of foam**, making it's application challenging. [3].

This study employs a range of additives, including **co-surfactant**, **polymer** and **nanoparticles**, with the primary focus on the use of foam for environmental remediation purposes in order to address this challenge.



Main objectives of the study:

- Highlight the challenges associated with foam stability in presence of LNAPL, particularly refined petroleum hydrocarbons;
- Investigate the synergetic effects of two environmentally friendly surfactants, sodium dodecyl sulfate (SDS) and cocamidopropyl hydroxysultaine (CAHS) on foam performance;
- Assess the stability of foam generated with two or more bio-additives in the presence of LNAPL, both in bulk and in highly permeable porous media.

2 Materials & Methods

Bulk foam experiments:

Foaming components:

- **Primary surfactant:** sodium dodecyl sulfate (SDS) - anionic
- **Co-surfactant:** cocamidopropyl hydroxysultaine (CAHS) - zwitterionic
- **Surfactant mixture:** SC (SDS + CAHS) - 50:50 ratio C_{tot} = 1%wt.
- **Bio-polymer:** xanthan gum (XG)
- **Nanoparticles (hydrophilic):** TM Ludox-50 (L50)

LNAPL:

Diesel oil (with antifoaming components)

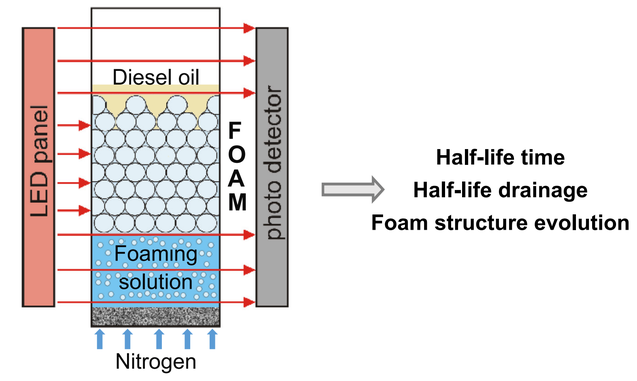


Fig. 1: Working principle of the Dynamic Foam Analyzer – DFA100.

1D column experiments:

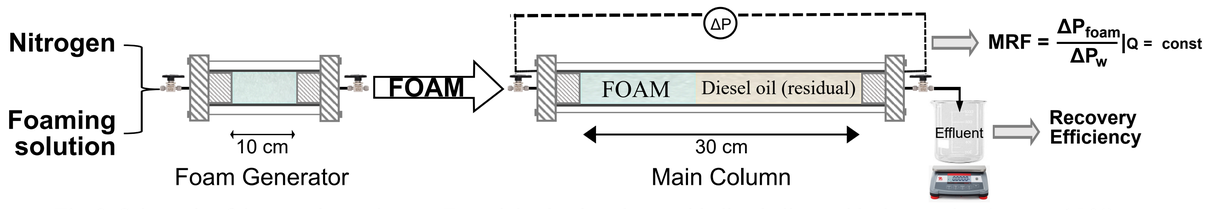


Fig. 2: Schematic of the experimental setup. Foam injection in column with diesel oil at residual saturation (approx. 15 %).

Porous Media	L (m)	D (m)	D (mm)	K (m^2)	Ø (-)	PV (mL)
Foam Generator	0.1	0.04	0.2-0.3	3.928E-11	0.36	54.45
Main column	0.3	0.04	0.4-1.3	2.855E-10	0.37	138.02

3 Results & discussion

Bulk foam experiments:

Synergy of surfactant mixture SC (SDS + CAHS)

Liquid drainage

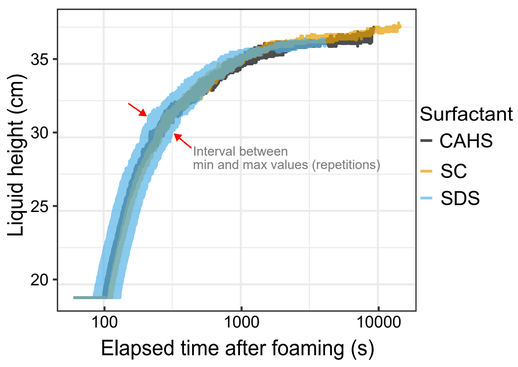


Fig.3: Drainage of bulk foam (amount of liquid drained from foam).

Diffusion of gas

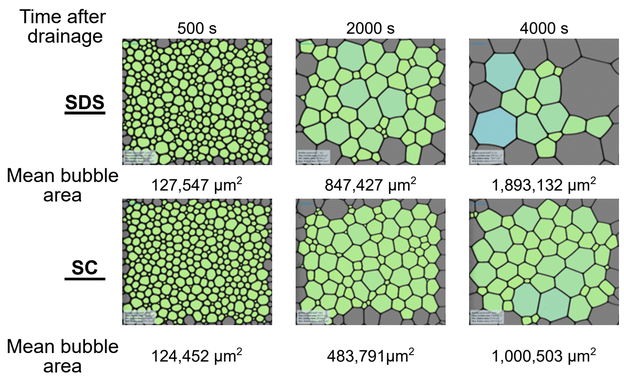


Fig.4: Evolution of foam structure (bubble size) over time after drainage.

- SC has no effect on foam liquid drainage
- SC reduces gas diffusion between foam bubbles due to densely packed interface (electrostatic forces)

Impact of diesel on foam stability

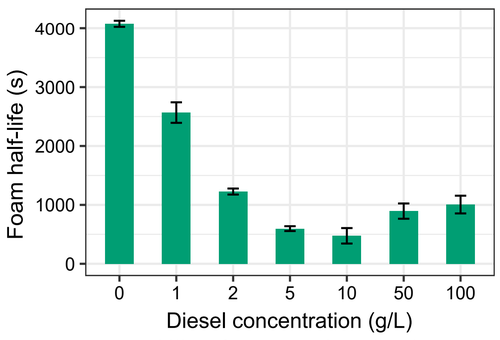


Fig.5: Foam stability of SDS at various diesel concentrations.

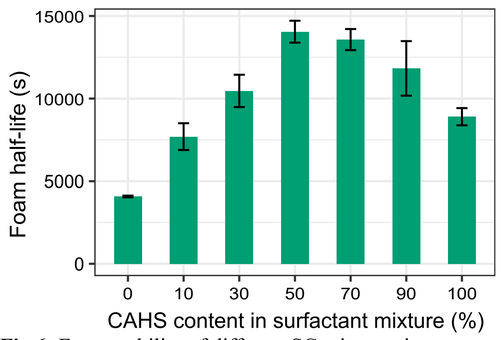


Fig.6: Foam stability of different SC mixtures in presence of diesel.

- Diesel at 10 g/L conc. shows the most destructive effect on foam. Half-life decreased more than 8 times
- Ratio of SDS and CAHS has crucial importance. 50:50 ratio shows the highest tolerance to diesel

Effect of additives (polymer & NPs) on foam stability in presence of diesel

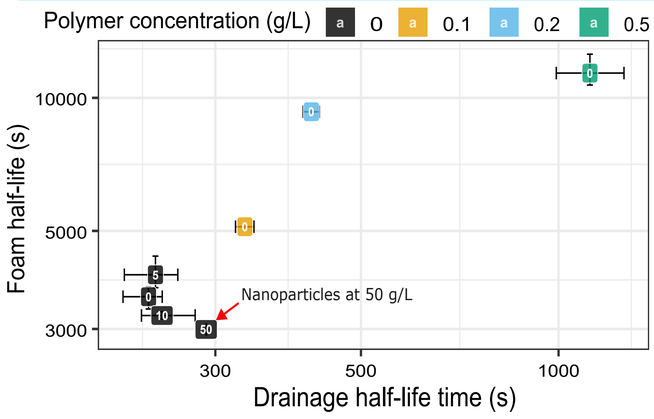


Fig.7: Stability of foam at various polymer and NPs conc. in presence of diesel.

- Foam stability remains unaffected by NPs at different concentrations
- The presence of polymer enhances the foam's stability
- XG at concentrations lower than 0.2 g/L significantly enhances both the foam half-life and the drainage half-life
- Beyond 0.2 g/L, XG improves only the drainage half-life

1D column experiments:

Effect of additives on foam performance in porous media

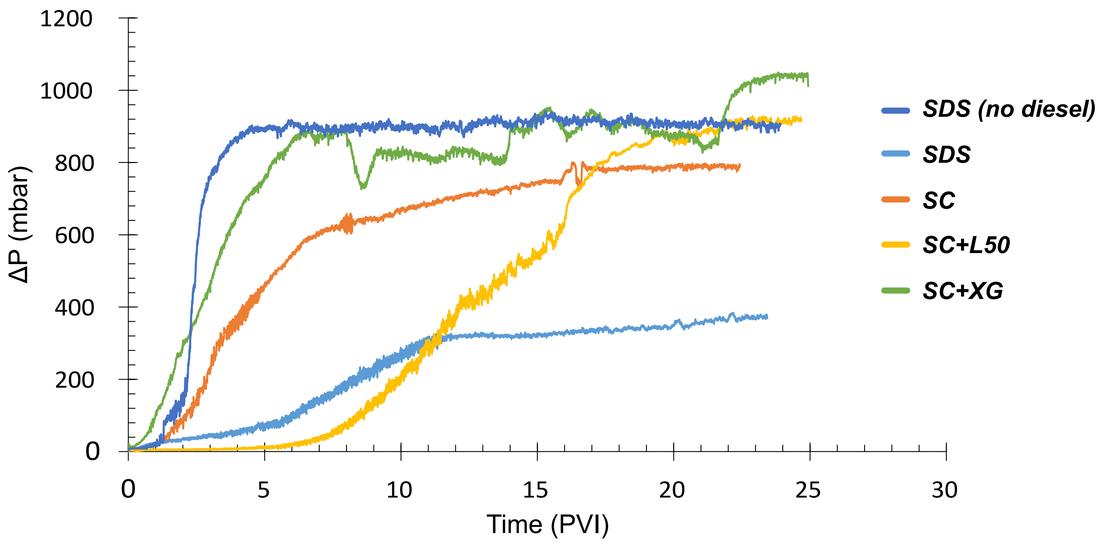


Fig.8: Pressure drop of as a function of injected PV for different foaming formulations.

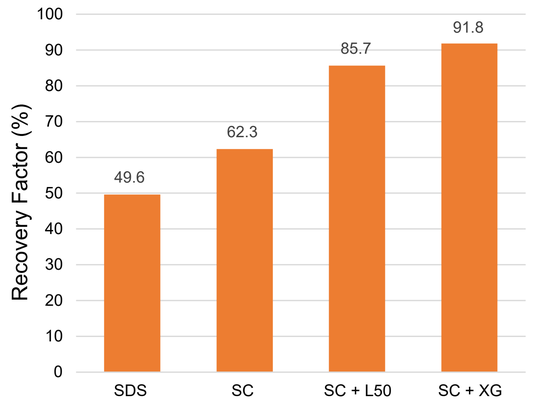


Fig.9: Recovery Factors of diesel for each employed foaming formulations.

- SDS alone has poor efficiency in porous media (similar to bulk foam exp.). ΔP reduced 2.4 times in presence of diesel. Maximum RF is 49.6 %.
- SC mixture is able to strengthen the foam with increased pressure drop more than 2 times, and increased recovery by 12.7 %
- NPs shows better performances in porous media than anticipated from bulk foam exp. ΔP increased more than 2.5 times, RF increased by 36%
- XG polymer has the best ability to enhance the foam. ΔP is almost 3 times higher than SDS alone. 91.8 % of Diesel is recovered by SC + XG mixture

4 Conclusions and perspectives

Main conclusions:

- Diesel has detrimental effect on foam stability both in bulk and porous media
- Synergy in SC surfactant mixture improves stability of foam with and without diesel. The ratio of SDS and CAHS was identified as crucial, with a 50:50 ratio demonstrating the highest tolerance to diesel and improved foam stability
- XG polymer at lower concentrations up to 0.2 g/L drasticaly improves bulk foam stability and noticeably enhances recovery of diesel in highly permeable porous media
- Nanoparticles require additional study since their behaviour is not trivial

References:

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[2] J. Maire and N. Fatin-Rouge, "Surfactant foam flushing for in situ removal of DNAPLs in shallow soils," J. Hazard. Mater., vol. 321, pp. 247–255, Jan. 2017, doi: 10.1016/J.JHAZMAT.2016.09.017.
[3] N. Forey, O. Atteia, A. Omari, and H. Bertin, "Saponin foam for soil remediation: On the use of polymer or solid particles to enhance foam resistance against oil," J. Contam. Hydrol., vol. 228, no. April, 2020, doi: 10.1016/j.jconhyd.2019.103560.

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