Flow-Dependent Retention of Zwitterionic Surfactants in Carbonates

Pablo A. Godoy [1], Luis Maqueira [2], Tatiana Berna [2], Leandro F. Lopes [2], Aurora Pérez-Gramatges [1,2]

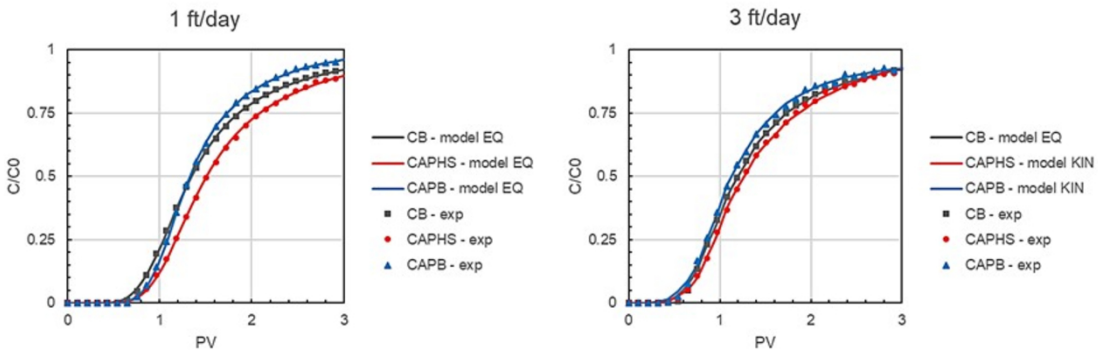
[1] Department of Chemistry, Pontifical Catholic University of Rio de Janeiro (PUC-Rio), Rio de Janeiro, Brazil
[2] Laboratory of Physical Chemistry of Surfactants (LASURF), Pontifical Catholic University of Rio de Janeiro (PUC-Rio), Rio de Janeiro, Brazil

aurora@puc-rio.br

Retention of surfactants in carbonate porous media emerges from coupled processes at the solid–liquid interface and in the flowing aqueous phase, yet static adsorption and dynamic transport are often analysed separately. Furthermore, although adsorption depends on surfactant structure, brine chemistry, rock properties, and flow conditions, most studies rely on static tests or single-flow-rate experiments, which do not fully represent dynamic reservoir conditions. Here, we relate previously established interfacial adsorption behaviour to new coreflooding results for three zwitterionic surfactants: cocamidopropyl betaine (CAPB), cocamidopropyl hydroxysultaine (CAPHS), and cetyl betaine (CB). Static adsorption studies on mineral surfaces revealed non-monotonic isotherms not captured by classical models and supported a three-step mechanism involving cooperative adsorption, surface aggregation, and micelle-induced desorption [1]. This interfacial framework provides a mechanistic basis for interpreting adsorption under flow, where retention depends on both surface affinity and transport conditions.

Dynamic adsorption was evaluated from Li-tracer and surfactant breakthrough curves in high-temperature/high-pressure coreflooding experiments using the same Indiana limestone core at injection rates of 1 and 3 ft/day, thereby isolating flow-rate effects from lithological variability. Surfactant concentrations were determined by HPLC-DAD/RID, and the breakthrough curves were modelled to assess the effect of injection rate within a consistent transport framework. The results show that increasing injection rate attenuates surfactant-specific retention and shifts the system away from local equilibrium. At low flow rate, longer residence times favour adsorption/desorption equilibration and amplify differences associated with surfactant structure and interfacial interactions. At higher flow rate, advective transport and hydrodynamic dispersion become more influential, limiting mass transfer to the carbonate surface and promoting a more kinetics-dominated response. This perspective places surfactant retention in carbonates within a unified colloid-and-interface framework, with implications for surfactant selection and injection strategies in subsurface applications, including enhanced oil recovery and geological CO2 storage.

Keywords:
Zwitterionic surfactants; dynamic adsorption; solid-liquid interfaces; adsorption/desorption kinetics; carbonate porous media



Experimental and modelled breakthrough curves for zwitterionic surfactants during coreflooding in Indiana limestone at 1 and 3 ft/day, comparing equilibrium and kinetic adsorption models

References:

[1] Pablo A. Godoy. Luis Maqueira. Aurora Pérez-Gramatges. *Langmuir* 41(35) 23726. 2025.

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