Synergistic Stabilization and Rheology of Sodium Alginate Gel Foams for Subsurface Carbon Storage and Enhanced Oil Recovery

Sodium alginate (SA) gel foams are gaining attention as high-performance fluids for subsurface applications, including geological carbon storage and enhanced oil recovery (EOR). In this study, we systematically investigate the synergistic stabilization and rheological behavior of sodium alginate gel foams with eco-friendly foaming agents. A series of gel foams were prepared by varying surfactant and SA concentration, and the type of crosslinking agents. The foam stability and rheological properties were evaluated under different salinity and temperature conditions to simulate reservoir environments. Foam drainage time and coarsening behaviours were used to estimate stability, while oscillatory and steady-state rheological tests were conducted to characterise viscoelasticity and flow behaviour. The results reveal that both the concentration of SA and the type of crosslinker significantly influence the gel network structure and foam stability. The rheological measurements show that the optimised gel foams exhibit Non-Newtonian behaviour and high elasticity, which are essential for controlling mobility in porous media. These findings provide fundamental insights into the design of stable, biodegradable gel foams tailored for harsh subsurface conditions. The study also highlights the potential of combining natural polymers with green surfactants to develop environmentally friendly formulations with tunable properties, offering new strategies for sustainable reservoir engineering and fluid control technologies.