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Application of Fractional Flow Theory to Foams in Porous Media

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Abstract

Due to its low viscosity and density, gas phase injected into porous media leads to viscous fingering, gravity segregation and channelling. The ability of foam to reduce gas mobility helps mitigate these problems by improving the sweep profile and increasing overall oil recovery. Although foam is believed to be a promising means to improve oil recovery, accurate prediction of its performance is hampered due to complicated foam rheology in porous media.

Mechanisms of foam displacement in porous media are investigated by the fractional flow theory in this study, incorporating fully mechanistic foam descriptions. During the change in total injection velocity by 8.15 times, the shape of fractional flow curves changes significantly, which in turn affects sweep efficiency and pressure profile markedly. The analytical solutions are in good agreement with recent mechanistic foam simulations in terms of foam texture, location of displacement front, saturation profile and pressure distribution.

The fractional flow theory with a new foam model in this study explains many features of conventional foam-generation experiments successfully: a weak-foam state at low injection velocity and a strong-foam state at high injection velocity, the transition from weak-foam to strong-foam state with a stepwise increase in injection velocity, the hysteresis associated with foam generation, and the effect of foam quality on foam generation. It should also be noted that the catastrophic nature of foam rheology observed in recent experimental and modelling studies are fully captured showing multiple solutions corresponding to weak-, intermediate- and strong-foam states. Construction of a three-dimensional surface of fractional flow curves makes it possible to analyze complicated foam mechanisms more conveniently.

When applied to gas injection (*i.e.*, fractional flow of water = 0), the method in this study shows that there exist two possible solutions: one with an immediate attainment of strong-foam state, exhibiting the water saturation behind the shock front near the limiting water saturation; and the other a weak-foam state with a long tail of spreading waves. Foam simulation shows that the selection between the two solutions is determined by the value of a

dynamic parameter, which describes how actively lamellae are created and destroyed in porous media.