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Modeling of CO2-Foam Rheology for Improved Injectivity Prediction in CCUS Processes

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Foam is appealing for carbon sequestration due to its remarkable effectiveness in gas-mobility reduction and thus gas sweep improvement (Rossen et al., 2020). Nevertheless, the considerable gas-mobility reduction by foam in the near-well region imposes a concern over foam injectivity. Shear-thinning rheology helps injectivity. Kim et al. (2005) and others show that CO2 foam is strongly shear thinning, with respect to both gas (Ug) and water (Uw) superficial velocities at low foam quality (fg, volumetric gas fraction in foam), as seen from the lower left figure of the graphical abstract. The shear-thinning behavior with respect to Ug has been represented in the widely used foam model, STARS (Computer Modeling Group, 2015). However, no currently applied foam models have yet accounted for the shear-thinning rheology of foam with respect to Uw. Such behavior features upward-tilting pressure-gradient contours with increasing Uw (see the graphical abstract, lower-left figure). Effective modeling of foam rheology is in particular crucial to accurate prediction of foam injectivity. Otherwise, the injectivity would be underestimated, misleading feasibility evaluation of a foam injection process.

Kim et al. (2005) identify a cause for the non-Newtonian foam rheology at wet conditions based on drag force on foam films (Hirasaki and Lawson, 1985): wet conditions create thicker water films along pore walls, leading to a reduction in drag force. In this study, we investigate how to incorporate this effect into the widely used STARS model. Specifically, a simple, semi-empirical equation is developed as a function of water saturation, to relate the effect of drag force to water saturation. The parameters involved in the equation can be easily estimated by fitting to steady-state foam data. The procedure for fitting model parameters is given and illustrated with examples (see fit to data in graphical abstract, left figure, in right figure). We also show how to couple this equation with the STARS foam model. The modified STARS model, incorporating the drag-force mechanism, is tested by fitting to steady-state data for both N2 and CO2 foam. The improved fit to the data verifies the validity of the new algorithm in representing foam rheology at low qualities (wet conditions).

In field applications, foam is usually injected through a surfactant-alternating-gas (SAG) slug mode. The injectivity of the process is primarily dominated by the injectivity of liquid slugs. Gong et al. (2020) using X-ray CT imaging of corefloods reveal that liquid injection forms fingers through in-situ foam and dissolves CO2 nearby, improving its injectivity. In addition to that, the shear-thinning rheology of foam further improves the injectivity. Therefore, considering these mechanisms improves the prediction accuracy of the injectivity of SAG foam processes. Further research is needed regarding the effect of foam rheology on liquid injectivity on the field scale.

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