Comparison Between Flow Simulations and Foam Experiments in Porous Media

R.R. Thorat[1], H. Bruining[1]

[1]Petroleum Engineering, CiTG, TU Delft, Delft, The Netherlands

Abstract

Recovery of oil by gas injection is usually inefficient due to the low viscosity of the gas, which results in bypassing of the oil without driving it towards the production well. By adding surfactant solutions it is possible to get in-situ foam formation. Foam has a much higher "viscosity" and hence does not bypass the oil, leading to an enhanced oil recovery. Other applications of foam comprise flow diversion, i.e., blocking watered out layers and forcing production from oil containing layers.
In this context, the mechanisms of foam propagation are studied experimentally and theoretically. We measured the pressure gradient in unconsolidated sand and Bentheimer sandstone cores to improve the understanding of foam propagation. In order to interpret the experiment we simulated the foam propagation process with a 1-D model along coordinate x. The model leads to three equations, i.e., the pressure equation, the water balance equation and the foam generation equation , which includes a source term that describes foam formation. The source term is parameterized using the experimental results. Initial and boundary conditions were taken from the experiment. We use COMSOL Multiphysics® to solve the equations after converting to weak form. Fig. 1 shows the flow cell with the points where the pressure drop was measured.
As for the simulation, a trial and error method was used to find parameter values to fit the simulation profile to the experimental curve. We describe in detail how the parameter values extracted from simulation can be used to describe the underlying physics of foam flow through porous media.
Fig. 2 shows a comparison between the pressure drop obtained from the experimental results and the COMSOL Multiphysics® simulations. The agreement is good, but we stress that we use empirical expressions for the source term.
Fig.3 shows the pressure equation. where k (kr) stands for the (relative) permeability, s for the water saturation, mu for viscosities, cw for the water compressibility, phi for the porosity and rho for the density. The sub-indexes w, g indicate water and gas phase respectively. We use mu_f to indicate the foam viscosity. As initial value for the pressure we use where U_tot is total velocity and l is length of the core. In the same way we also defined the water saturation equation and foam generation equation, which includes a source term that describes foam formation. The source term is parameterized using the experimental results. Initial and boundary conditions were taken from the experiment.

Reference

11/12 abstract reviewed by Laura

Figures used in the abstract

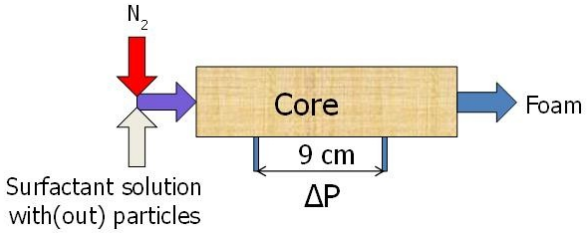

Figure 1: Experimental set up for the foam flow

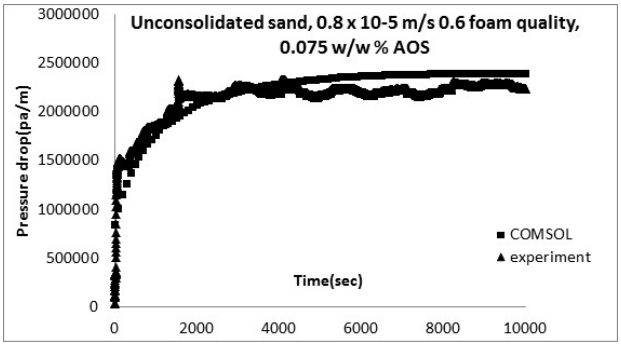

Figure 2: Comparison between experimental result and COMSOL simulation

$$\varphi\left(c_w s+\frac{(1-s)}{p}\right)\partial_t p+\frac{kk_{rg}(s)}{\mu_f(n)}\left(\partial_x p-\rho(p)g\right)+$$
$$\frac{k_{rw}(s)}{\mu_w}\left(\partial_x p-\rho_w g\right)+\frac{kk_{rg}(s)/p}{\mu_f(n)}\left(\partial_x p-\rho(p)g\right)+\frac{kk_{rw}(s)c_w}{\mu}\left(\partial_x p-\rho(p)g\right)\partial_x p,$$

Figure 3: The pressure equation