Non-Newtonian behaviour of foam flow in porous media: experiments and upscaling

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Abstract

Foam injection in porous media has been investigated for a variety of applications in the oil industry, especially, for Enhanced Oil Recovery (EOR). Foam injection technics developed for EOR can also be applied to soil remediation processes to remove Non-Aqueous Phase Liquids (NAPL) from aquifers. The primary purpose of foam injection in soil remediation operations is to control the permeability of porous media to divert the flow from high to low permeable zones in aquifers. There are some major differences between oil reservoirs and aquifers. For instance, porous media in oil reservoirs are mainly low permeable and consolidated, and under high pressure and temperature conditions. While, polluted aquifers are mainly unconsolidated and highly permeable. As a consequence of these differences, *in-situ* foam generation in aquifers is questionable, and also foam flow in aquifers calls upon further investigation.

Generally, understanding of foam flow in porous media is hampered due to complex behaviour of foam and apparent contradictions in foam studies. For example, some authors indicated Newtonian [1] behaviour of foam flowing in porous media, others shear-thinning [2], shear-thickening [3], a mixture of Newtonian and shear-thinning [4] or dependent on foam quality (foam gas volume fraction) [5]. In addition, it must be noted that most studies presented in the literature concern low permeable media for EOR applications.

The objective of this study is to determine, experimentally, the rheological behaviour of bulk foam and to investigate foam flow in high permeable unconsolidated porous media by performing numerous laboratory experiments and finally to scale-up, theoretically and/or numerically, the foam flow from pore to Darcy scales.

At first, the rheological parameters of the bulk foam, pre-generated using a fine sand-packed column, were measured by a rheometer. The bulk foam for 85 % foam quality was found to have a non-Newtonian yield stress fluid behaviour, which could be correctly represented by the Herschel-Bulkley model. Then, the pre-generated foam has been injected into fine sand and also calibrated glass beads packed columns (4 cm internal diameter, 40 cm height). In each experiment, a fixed quality foam is injected for different total flow rates, where gas and surfactant solution rates are changed simultaneously. Pressure drops are measured over the 1D column for each flow rate, thus allowing to investigate the macroscopic flow rate (Q) – pressure gradient (∇P) relationship. The macroscopic flow of 85% and below foam quality for various unconsolidated porous media clearly leads to $Q(\nabla P)$ featuring a yield stress behaviour.

The experimental results are the basis to validate foam upscaling in porous media, where foam was considered as a single-phase Herschel-Bulkley fluid. This assumption is valid when the bubble size is much smaller than the pore size. The closure problem obtained by homogenization from the general case of non-Newtonian fluids flow in porous media [6] is solved numerically for yield stress fluids for different 2D and 3D unit cell geometries.

In this talk, experimental and numerical results will be presented, and the experimental data will be compared to the upscaled results.

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