Analyzing the effects of polymer entrapment on enhanced oil recovery using a PDE model (MEP)

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General introduction

In the coming decades demand for oil will increase due to the increasing global energy, even though new/renewable energy sources are developped. Currently however only a part of the oil contained in a reservoir is recovered. An oil reservoir (and the subsurface in general) can be viewed as a sponge: it consists of solid material (the rock grains) and void space (the pores). The typical dimensions of a single pore are of the order $10^{-6} - 10^{-3}$m. These pores form a pore network; significant fluid flow through this network is possible, provided enough pressure is applied. In a reservoir the oil droplets are located in the pores.

In the primary recovery stage, a well is drilled in the reservoir and part of the oil flows out due to the natural pressure; 90-95% of the oil remains in the reservoir. After the primary recovery stage part of the wells is converted to injection wells to inject water in the reservoir in order to push the oil towards the production wells. However still only 30-40% of the original oil in place can be recovered after this secondary production stage. One of the reasons is the formation of so called viscous fingers. These viscous finger bypass most of the oil and effectively form a water channel from inlet to outlet, which means that eventually only water is produced (see e.g. [1] and the figure therein). A number of enhanced oil recovery methods are aimed at the prevention of these viscous fingers.

The fingers are mainly caused by the unfavorable mobility ratio between the displacing water and oil (displacement is usually unstable if the displacing fluid is less viscous than the displace fluid). One solution is the addition of a mixture of chemicals/polymers to the injected fluid in order to improve the mobility ratio. In estimating the amount of polymers often the adsorption of polymer on the rock and the entrapment of polymers in the reservoir is neglected. The adsorption and entrapment effectively mean that some of the polymer does not reach the oil-water interface - neglecting these effects may lead to an under estimation of the amount of polymer needed. Note that these surfactants can be expensive so it is important to estimate how much additional oil can be recovered to warant the investment and to decide whether the process is economically viable.

Mathematical modelling

Two phases (water and oil) are flowing simultaneously through the porous medium (hence two phase flow). The fraction of the void space occupied by the water is called the water saturation $S_w(\mathbf{x}, t)$; the oil fraction is called the oil saturation $S_0(\mathbf{x}, t)$. The two phases are assumed to be immiscible which means that oil saturation S_o can be expressed in terms of water saturation as $S_o = 1 - S_w$. The polymer is assumed to dissolve in the water only; polymer concenctration C is modelled using a reaction convection equation, where the reaction term models the adsorption and entrapment of polymer.

Mass conservation of water leads to a convection diffusion equation for S_w; all physics (two phase behaviour, viscosity, capillarity) is encoded via the highly nonlinear coefficients. The viscosity of the water phase depends on the polymer concenctration, which means that we will have a set of two coupled, nonlinear PDEs. The resulting model equations are solved analytically for the 1D single phase and numerically for the 1D two phase case in [2], where it is indeed shown that the polymer concenctration at the front is significantly lower than the injection concenctration.

Project description

In this project we will extend the work of [2] and we will solve the two-phase problem numerically. We will investigate the stability of the front as a function of our model parameters. This will allow us to determine the minimal amount of polymer required to maintain a stable front.

Literature

References

[1] G.M. Homsy. Viscous fingering in porous media. *Annual Review of Fluid Mechanics*, 19:271–311, 1987.

[2] B. Meulenbroek, R. Farajzadeh, and J. Bruining. Analytical modeling of history-dependent polymer retention in porous media, impact of mechanical entrapment on the design of mobility control in chemical enhanced oil recovery. 2020.