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Recent Contributions to the Study of Immiscible Viscous Fingering

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When viscous dominated fluid -> fluid displacements in a porous medium take place, and the viscosity of the displacing fluid is significantly lower than that of the displaced fluid, then an instability occurs known as viscous fingering (VF). The 2 fluids may be completely miscible or immiscible but in porous media the more complex phenomenon to reproduce both experimentally and in numerical simulations is immiscible viscous fingering; e.g. when water (viscosity, mw) displaces a very viscous oil (viscosity, mo) from a porous medium; i.e. when (mo/mw) » 1.

Many publications on immiscible VF have been produced over the last few decades, the vast majority of this being theoretical/numerical. In contrast, there are only a few published studies presenting experimental results on two phase (water/viscous oil) displacements showing VF with a full dataset which can be used to test any of the proposed models or numerical simulation methods. A "full dataset"includes finger patterns, oil recoveries, watercuts and pressure profiles across the system over time (vs. PV). Such datasets have become available in the last decade from researchers in Norway giving the details of several VF water -> viscous oil displacement experiments (and tertiary polymer floods) in 2D sandstone slabs for a wide range of viscosity ratios, (mo/mw) ~ 10 –7000.

Even before the above data was available, there have been many attempts to simulate immiscible VF by direct numerical simulation; i.e. solving the PDEs of 2 phase flow directly. Virtually all of this work produced some evidence of numerical instability and weak fingering, but the results did not resemble the highly ramified structure of observed experimental immiscible fingering. Many researchers identified the problem as being due to the inadequate numerics; i.e. current numerical methods for solving the transport equation did not capture the details of fingering due to numerical errors, e.g. numerical dispersion. Others, including the present authors, believed that the lack of finger resolution was not in the numerics but in the physics and in the "approach"to the problem. This was demonstrated in a paper in 2020 which showed that by starting from the fractional flow function as the principal input (fw*) and then choosing the relative permeabilities (kro and krw) such that the total mobility was maximized, very good resolved immiscible fingering could be obtained. In 3 further papers, this method was applied directly to the published immiscible VF experiments described above, and very good to excellent agreement was found for all the modelled quantities (finger patterns, oil recoveries, watercuts and pressure drops). Furthermore, the method without further adjustment could also predict the results for the tertiary polymer floods carried out after the waterfloods.

This talk will present a review and summary of these results and will present new extended results of this approach to include (1) the effects of capillary pressure; (ii) the scaling of how viscous fingering interacts with gravity (varying the viscous /gravity scaling group), and (iii) how the method has been upscaled to model waterflooding and polymer flooding in the field.

Participation

In-Person

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