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Non-thermal Fluctuations in Stead-State Multiphase Flow in Porous Media

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Relative permeability is typically measured in core flooding experiments where the so-called steady-state method is preferred over other approaches because of the large accessible saturation range, better control and interpretability compared with other methods. Wetting and non-wetting phases are co-injected at a range of fractional flows fw and the resulting pressure drop and saturation are monitored. These experiments are typically performed on cylindrical samples of preferentially homogeneous porous media (e.g. rock) of several centimeters in length and diameter. The implicit assumption is that these samples are sufficiently large to represent Darcy scale flow which is supported by the fact that e.g. in homogeneous sandstone rock the porosity and permeability representative elementary volume (REV) is just 3-4 mm. The common understanding of Darcy-scale flow regimes is that pore scale phenomena and their signature should have averaged out at the scale of representative elementary volumes (REV) and above. However, many steady-state relative permeability experiments exhibit temporal variations in key parameters such as pressure drop and saturation.

In the past these fluctuations have been largely mistaken for experimental artefacts caused by e.g. membrane-based back pressure regulators. However, a number of experiments where such instrument-based artefacts can be ruled out suggest that there is an intrinsic cause of these fluctuations related to the underlying pore scale flow regimes.

By comparing the signature of the fluctuations between a centimeter scale experiment with in-situ saturation monitoring and a pore scale experiments with 3D imaging by synchrotron beamline-based fast X-ray computed micro tomography we establish that large fluctuations which are associated with a capillary energy scale (many orders of magnitude larger than thermal fluctuations) are much larger than instrumental noise. Instead, they are caused by cascades of pore scale displacement events involving hundreds to thousands of pores. The fluctuations exhibit non-Gaussian statistics and are in some cases repetitive and even oscillatory manifesting themselves in repetitive sequences of travelling saturation waves. Their origin can be traced back to the non-wetting phase cluster ganglion dynamics at pore scale which involve breakup and coalescence processes depending on the fractional flow. Breakup and coalescence processes follow "trajectories"in a "phase diagram"defined by fractional flow and capillary number which can be used to categorize flow regimes. Connected pathway flow would be represented by a fixed point.

Ganglion dynamics occurred even at very small capillary numbers i.e. in a by macroscopic definition clearly capillary-dominated regime which suggests that breakup and coalescence processes are not caused by viscous mobilization. Instead, displacement processes associated with the fractional flow conditions trigger capillary instabilities in a largely metastable pore scale fluid configuration which initiate avalanche-like cascades of displacement events involving a significant number of pores which can lead to not only notable pressure but also saturation changes at the centimeter scale.

Since the steady-state experiment is primarily a stationary state (rather than a steady-state) these fluctuations do average out when applying sufficiently time averages.

Time Block Preference

Time Block A (09:00-12:00 CET)

References

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