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Averaged fluid distribution and its variability in heterogeneous formations

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The macroscopic interface between fluids (which is meant as the transition zone, where there is a sharp change between displacing and displaced fluid on the continuum scale) during immiscible displacement has a strong influence on mass transfer during the flow process. In heterogeneous media, the macroscopic interface will not be a straight line, but will be heterogeneously distributed. Important criteria to quantify the macroscopic interface are the front roughness and the averaged saturation at the front. However, macroscopic interfaces between the fluids also exist behind the displacement front, if displaced fluid is cut off either because it is immobilized by surrounding displacing fluid or because it is located in zones with very low permeability. The cut-off could be called quasi-trapping, as the fluid will be displaced eventually, but on time scales that are in the range, or longer than the time scale of interest. If displaced fluid is located in zones with very low permeability, the quasi-trapping of displaced fluid is related to the flow parameters and structure of the porous medium. In the second case, the amount of quasi-trapping depends also on the fluid properties and the flow regime.

We analyze the front roughness and quasi-trapping of fluid and the related macroscopic interface during immiscible displacement processes using laboratory experiments and numerical simulations of displacement for different flow regimes in heterogeneous media with different background-inclusion patterns. We also discuss upscaled modeling approaches that predict the averaged fluid distribution. Averaged front roughness could be captured by a dispersion term in the flow equation, while quasi-trapped fluid could be represented by describing the flow process as dual-continuum approach and capturing the exchange between mobile and immobile zones as a source / sink term in the flow equation for the mobile domain. It will also be discussed, if the averaged saturation could provide measures for the macroscopic interface between displacing and displaced fluid.