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Impacts of Controlled Surface Roughness on Fluid Trapping in Glass Micromodels: Implications for Subsurface Multiphase Flow

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Pore-scale surface roughness occurs in varying degrees and forms within geologic media due to authigenic cement coatings and clay minerals. Such roughness increases the surface area contacted by fluids and chemical additives during subsurface operations such as enhanced oil recovery, storage of hazardous waste, carbon storage and sequestration, and non-aqueous phase liquid (NAPL) remediation from groundwater aquifers.

We utilize glass microfluidic chips (micromodels) to investigate the impact of surface roughness on trapped phase saturations after immiscible two-phase drainage and imbibition experiments. A new method is developed for incorporating surface roughness into glass microfluidic chips which allows tuning of roughness spatial distribution and height variation. Micromodels with rough and smooth surfaces are fabricated and light microscopy and image processing techniques are utilized to capture and quantify fluid phase distributions throughout each experiment. Imbibition experiments are conducted by placings water droplets on the inlet port of the micromodels, whereupon the liquid spontaneously enters the chip. Air is injected at a constant flow rate into micromodels filled with crude oil to replicate drainage.

It is found that surface roughness with an average height of approximately 10% of the matrix pore depth increases trapped air saturation by ten to twenty times following spontaneous imbibition. This behavior is due to an increase in the occurrence of snap-off at throats and contact line pinning within pores that is enhanced by surface roughness. Drainage experiments are performed to investigate the impact of surface roughness on viscous fingering. Each micromodel is initially fully saturated with crude oil (100 centipoise viscosity) while air is subsequently injected at a constant flow rate. We find that the presence of surface roughness broadens the viscous fingering dendrites but trapped wetting phase saturation remains close to trapped saturation measured in smooth micromodels. Finally, we investigate the impact of surface roughness for a single fracture in a micromodel. This combination replicates the presence of large fractures within reservoirs and can have a significant effect on the efficacy of subsurface fluid production operations. We find that the roughness of large fractures does not affect trapped saturation significantly (less than 5%).

The various immiscible two-phase flow experiments considered in our work are valuable for determining the residual hydrocarbon saturation after water flooding a reservoir, establishing the flowback subsequent to hydraulic fracturing of a tight formation, and estimating the optimum injection volume for removing NAPL from aquifers. In addition, the method of incorporating controlled surface roughness into micromodels can be implemented as a tool for investigating surfactant absorption in chemical oil recovery, dispersion of carbon dioxide during carbon sequestration, and interpretation of tracer breakthrough profiles. Finally, the experimental results and workflow presented in this study can assist in verifying the reliability of numerical simulations of multiphase subsurface operations.

References

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