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A physics-based model to predict the impact of horizontal layers on CO2 plume migration

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Geologic carbon sequestration can play an important role in reducing the amount of greenhouse gasses emitted to the atmosphere. To ensure the long-term security of the injected CO2, a good understanding of the fate of the plume is needed. Small scale (mm-m scale) rock structure heterogeneities impact the local capillary forces and, therefore, a capillary potential at the scale of the heterogeneity can exist. This can result in capillary induced flows and trapping and can have significant impact on the migration of the injected CO2. As a result the lateral migration of the CO2 plume is often not well predicted by reservoir simulators where small-scale rock heterogeneity is not taken into account. Small-scale rock heterogeneity can be incorporated into larger scale models by using upscaled effective multi-phase flow parameters. These effective parameters are flow-rate dependent due to the dependence of the saturation distribution on the viscous-capillary force balance. We present a new physics-based model that can obtain effective flow-rate dependent relative permeability and capillary pressure functions in horizontally layered systems over the full velocity range, analytically (Figure 1). For this purpose a new capillary number, RVC, has been derived that correctly captures the viscous-capillary force balance for horizontally layered systems. The model is based on the fractional flow approach and the obtained effective flow-rate dependent fractional flow functions can be implemented into an extended radial Buckley-Leverett solution to look at the impact of mm-m scale heterogeneity on the frontal advance of the CO2 plume (Figure 2).The local RVC in the case of radial Buckley-Leverett systems is a function of two competing factors, the fractional flow of CO2 and flow-rate. Both factors decrease with radial distance, and the fractional flow of CO2 increases with time. A decrease in the fractional flow of CO2 moves the system towards the VL, while a decrease in flow-rate moves the system towards the CL. The counterbalance between those two factors determines, together with the absolute permeability, the permeability ratio, and aspect ratio of the layers, when and where the VL to CL transition occurs. When the system transitions from the VL to the CL the relative permeability of the CO2 phase increases, while the relative permeability of the water phase decreases. As a result, the CO2 plume travels further when the system moves towards the CL. Our work shows that for injection rates and volumes commonly used at injection sites, the CL is reached quickly suggesting that flow-rate dependency is only important during the initial phase of the injection period. If the objective is the prediction of the lateral extent of the plume at the end of the injection period, the use of CL saturation functions will be valid, even close to the injection well.

Time Block Preference

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

References

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