Effect of Crossflow and Heterogeneity on CO$_2$ Behaviour in Sandstone Oil Reservoirs

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Abstract

Understanding the behaviour of CO$_2$ in heterogeneous oil reservoir is very important for assessing both storage and enhanced oil recovery (EOR) opportunities. This paper presents the results of an experimental study into the effect of crossflow on ultimate oil recovery during miscible and immiscible CO$_2$ flooding in heterogeneous sandstone reservoirs.

For this study, heterogeneous samples were manufactured using natural sandstone rocks which were initially homogeneous. To accomplish this, homogeneous cylindrical rock samples of differing permeabilities were cut longitudinally into two halves. The heterogeneous samples was constructed simply by placing two halves each from samples of different permeability side by side to make up a single composite sample. Then, core-flooding experiments were conducted under reservoir conditions on the composite samples using a decane-brine-CO$_2$ fluid system. The miscibility was controlled in the experiments by changing the injection pressure (immiscible at 9.6 MPa and miscible at 17.23 MPa) at a constant temperature (343 K).

The results indicated that crossflow in the composite sample has an appreciable effect on the ultimate oil recovery (i.e. increasing oil recovery by 5% as a maximum). The degree of heterogeneity seems to strongly influence the effectiveness of crossflow during CO$_2$ EOR with the oil recovery decreasing as the permeability ratio (PR) between the two half plugs included in every samples increases. For instance, during miscible CO$_2$ flooding, a decrease in incremental oil recovery from 4.89% to 4.49% and eventually to only 1.74% occurred when the PR was increased 2.5, 5, and 12.5, respectively. These results suggest that a considerable channelling of the injected CO$_2$ through the high permeability layer reduces the amount of additional oil mobilised by crossflow. However, a different trend was observed for immiscible displacement affected by the average value of permeability of two layers. In this case, the oil recovery was 4.68%, 2.32% and 4.79% for increasing PR values of 2.5, 5 and 12.5, respectively. These results suggests that oil tends to move through the high permeability section due to gravity when the low permeability layer has a very low permeability value. Whereas, in the case of a high permeability value for the lower permeability layer the effect of crossflow neutralise due to passing of CO$_2$ through both layers.

For the layered system, crossflow is one of the mechanisms for recovery enhancement during an IOR/EOR process. Reservoir heterogeneity plays a critical role in the successes of IOR/EOR processes, but it has never been comprehensively quantified, especially for some emerging techniques. Thus, the results from this paper are very important to overcome the current challenges in capturing the importance of crossflow influence as well as mitigating the effect of geological uncertainties on current and future IOR/EOR projects. These results are also relevant in
understanding how CO₂ itself fundamentally behave in a heterogeneous reservoir with low and high permeability components.