Effect of CO$_2$-water Injection ratio on the co-optimization of oil recovery and CO$_2$ Storage in a SWAG Displacement Process

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Abstract

Carbon dioxide (CO$_2$) injection is known as an important Enhanced Oil Recovery (EOR) method. However, a low volumetric sweep efficiency has always been a technical issue for continuous CO$_2$ flooding because of high mobility and low density of CO$_2$ in comparison with those of other reservoir fluids. The low volumetric sweep leaves large volumes of bypassed oil in the reservoir which in turn leaves limited pore space available for CO$_2$ storage. Therefore, several mobility control methods have been trialed in laboratory and field pilot tests to improve the sweep efficiency. One mobility control method is CO$_2$ simultaneous water-and-gas (CO$_2$-SWAG) injection. The injected water displaces the oil which is bypassed by the CO$_2$ to enhance oil recovery. Recent laboratory studies have found that CO$_2$-water injection ratio (CWIR) in a CO$_2$-SWAG process can affect CO$_2$ relative permeability function (Kamali and Hussain, 2017, Kamali et al., 2017, Gong and Gu, 2015). An optimized CWIR reduces the CO$_2$ relative permeability, hence increasing the amount of CO$_2$ retained in the pore space. Although the previous studies have highlighted strong dependency of CO$_2$ relative permeability on CWIR, the number of experiments performed were limited to find the optimum value of CWIR.

In this study we performed laboratory experiments to find optimum CWIR to maximize oil recovery and CO$_2$ storage during CO$_2$-SWAG displacement in a Bentheimer sandstone. A 28cm long Bentheimer core sample was used for the study. Before the SWAG injection, the core was at irreducible water saturation. The oil phase is composed of 65% Hexane (C$_6$) and 35% Decane (C$_{10}$). Experiments were run at 1700psia and 70$^\circ$C which represents near-miscible conditions. Pure Supercritical CO$_2$ and distilled water are injected simultaneously into the core at a fixed CWIR. A total of 8 experiments were performed at CWIR of 0.0, 0.25, 0.50, 0.75, 0.9, 0.95, 0.996 and 1.0. CWIR of 0.0 and 1.0 represents water injection and continuous CO$_2$ injection, respectively while a CWIR of 0.996 represents supercritical CO$_2$ fully saturated with water at the experimental conditions. The produced fluids are collected in glass vials and are subsequently analyzed using the Gas Chromatography to quantify the produced water and hydrocarbons. A gas flowmeter is used to measure the mass rate of gas. The volume of the produced liquid and differential pressure across the core are continuously recorded during the experiment. A co-optimization function for CO$_2$ storage and oil recovery is calculated using the observed data from the experiment. A compositional commercial reservoir simulator is used to determine the CWIR dependent relative permeability functions. Pressure drop across the core, oil recovery and the mass of CO$_2$ stored are used as the matching parameters.

The results indicate that 0.75 is the optimum CWIR for the given experimental conditions. A remarkable reduction in CO$_2$ relative permeability was observed for CWIR 0.75 compared with continuous CO$_2$ injection (CWIR=1). Numerical simulations show that the reduced CO$_2$ mobility
led to a low velocity of CO₂ compared to water which in turn results in a reduced water-shielding effect more retention of CO₂ in the pore space. This led to more contact between CO₂ and oil and increased oil recovery rate and CO₂ storage efficiency. Hence, the co-optimization function improved significantly.

**Keywords:** CO₂-water injection ratio, SWAG; Enhanced Oil Recovery; Co-optimization; CO₂ storage

Reference

