Experimental Evaluation of Water/CO_2-flooding to Enhance Oil Recovery from Low-Permeability Reservoirs

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Summary

Low-permeability hydrocarbon resources have been under commercial development in Canada for the past two decades (e.g., Montney, Duvernay, and Bakken Formations). Although the use of multi-fractured horizontal wells enhances production, hydrocarbon recoveries remain low (5-10%) using the primary recovery scheme. Waterflooding has been trialed by operators to improve oil recoveries for reservoirs with permeabilities in the micro-Darcy to milli-Darcy range (Song and Yang, 2017). However, the existence of natural/induced fractures may limit waterflood applicability due to early water breakthrough and reduced recovery efficiency (Kharrat et al. 2021). CO_2 flooding has recently been explored as a strategy to further enhance hydrocarbon recovery in low-permeability reservoirs due to its reduced environmental footprint (Yu et al. 2021). However, recovery mechanisms and production controls for this scheme remain unclear in low-permeability reservoirs. The primary objectives of this study are to 1) evaluate EOR performance of continuous CO_2 flooding, following waterflooding, in a low-permeability siltstone reservoir, and 2) investigate geological and operational controls on recovery performance (e.g., rock permeability, porosity, fluid injection flowrate, injection pressure, etc.).

Samples / Method / Workflow

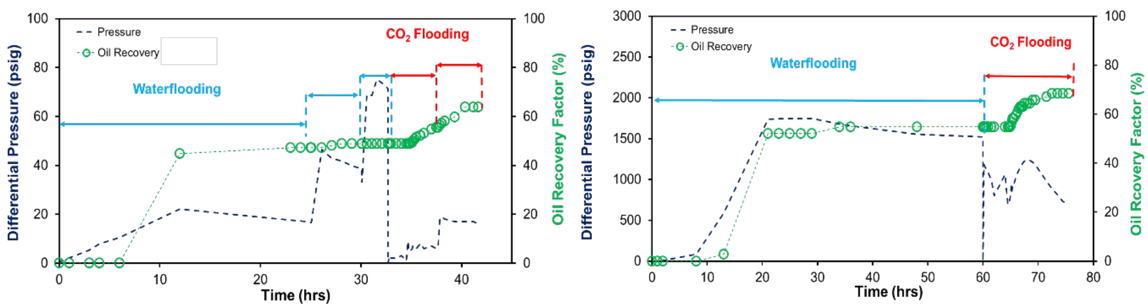
Two core plugs with a ~3.8 cm (1.5”) diameter and ~5.1 cm (2”) length were analyzed in this study. The core plugs were collected from two different wells drilling in a tight oil reservoir in Alberta (Canada), and cut parallel to bedding. Both of the core plug samples were subjected to screening petrophysical and geochemical tests prior to the EOR experiments. The key properties of the samples include: quartz content: 57-59 wt.%, swelling clay content: 0-6 wt.%, feldspar content: 9-12 wt.%, helium porosity: 12.6-15%, and slip-corrected (N_2) permeability (at net stress = 2000 psi): 0.04-1.07 md.

The experimental procedure included: 1) cleaning the core plug samples with toluene and methanol to remove residual hydrocarbons and salts, and drying at 100 ^oC; 2) measuring the stress-dependent gas (N_2) and liquid (brine) permeability under 500-2000 psi of effective stress to mimic reservoir stress conditions; 3) performing waterflooding with varied injecting rates (0.01-0.1 cc/min) for 4-4.5 pore volumes (PV) until no more oil was produced; and 4) conducting a suite of miscible continuous CO_2 flooding with rates of 0.05-0.1 cc/min for an additional 4.5 PV (under “in-situ” conditions). To allow a direct comparison, identical operational parameters (i.e., fluid injection rate, confining pressure, production pressure) were applied for water and CO_2-flooding of the two samples.

Results / Observations

Two sets of waterflooding tests were performed, followed by two sets of continuous CO_2 flooding tests. Recovery factors obtained from waterflooding were approximately 49-55% OOIP for the analyzed core plugs, with an additional 13-15% OOIP recovery obtained from miscible CO_2 flooding (**Fig. 1a** & **b**). A larger differential pressure was observed for the waterflooding experiments (75-1750 psi) compared to the CO_2 flooding experiments (20-1230 psi). For the same (or even higher) injection rates, the differential pressure was significantly (up to 30-75%) smaller for the CO_2 flooding experiments, indicating a higher injectivity of CO_2. This is mainly attributed to the lower viscosity of CO_2, and reduced capillary pressure in the rock. Water injection pressure for the lower-permeability core plug (up to 1750 psig, 0.04 md) was larger than for the higher permeability core plug (up to 75 psig, 1.07 md), suggesting that reservoir permeability controls waterflooding performance in low-permeability reservoirs.

The findings of this study will be beneficial to operators considering implementation of EOR schemes in low-permeability reservoirs of Alberta (Canada).



(a) (b)

Fig. 1 – Differential pressures and oil recoveries measured during waterflood and CO_2 flood experiments performed for two core plug samples with different permeabilities: **(a)** higher permeability sample (1.07 md), and **(b)** lower permeability sample (0.04 md).

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