Advanced Core/Cutting Analysis Methods for Evaluation of Enhanced Oil Recovery in Tight Oil and Liquid-Rich Gas Reservoirs

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Summary

Using a variety of advanced core/cuttings analysis methods, this work presents results from an ongoing laboratory study investigating the fundamental controls on enhanced oil recovery (EOR) processes in tight hydrocarbon reservoirs. The primary objectives are to 1) evaluate the influence of entrained hydrocarbon and organic matter (OM) on hydrocarbon storage and transport characteristics, 2) quantify stress-dependent unpropped/propped fracture permeability and dynamic rock mechanical properties that are used to constrain numerical modeling and 3) examine geological controls (organic/inorganic contents, thermal maturity, porosity, pore size distribution, surface area) on liquid/relative permeability of tight rocks. Selected laboratory results from multiple Western Canadian tight oil and liquid-rich gas reservoirs (Montney, Duvernay, and Bakken) are provided and discussed. Further, this study highlights the application of laboratory results for constraining numerical simulation studies used to evaluate the technical viability of EOR techniques to improve oil recovery from these reservoirs. Combined with necessary field and simulation studies, the innovative experimental workflows provided herein have important applications for targeting specific zones within the reservoirs of interest. Selection of these "sweetspots" along the well length could prove critical for maximizing gas storage/transport during cyclic solvent injection for EOR applications.

Introduction

Development of unconventional hydrocarbon resources has been historically focused on primary recovery (depletion) with multi-fractured horizontal wells (MFHWs). However, the current primary production processes are inefficient with low recoveries (<10% of oil in place), and do not offer a solution to reducing Canada's/global greenhouse gas emissions. A potential solution to this problem is to inject CO_2 (for tight gas reservoirs) and (re)inject lean/rich-gas and/or CO_2 (for tight oil reservoirs) back into MFHWs for the simultaneous purpose of increasing hydrocarbon recovery and reducing greenhouse gas (CO_2 and CH_4) emissions. The cyclic solvent (CO_2, lean/rich-gas) injection processes (commonly referred to as huff'n'puff) are potentially attractive mechanisms for enhanced oil recovery (EOR) application because, unlike flooding scenarios (dedicated injection and producing wells), large expenditures on specialized facilities, in-field pipelines and well conversions are unnecessary. Despite these advantages, industry requires critical laboratory data and evaluation methods – in addition to necessary field studies – to support simulation studies that provide input for pilot design purposes.

Methods

An innovative multidisciplinary approach that combines routine and non-routine experimental techniques is used for a selected sample suite from multiple prolific tight oil and liquid-rich gas reservoirs in Western Canada (Montney, Duvernay, and Bakken). The characterizing techniques are Rock-Eval pyrolysis, extended slow-heating (ESH) Rock-Eval pyrolysis (Sanei et al., 2015), helium pycnometry (grain density, porosity); low-pressure gas (N_2, CO_2) adsorption (surface area, pore size distribution); crushed-rock gas (N_2, CO_2) permeability; matrix/unpropped/propped fracture permeability (N_2) and ultrasonic velocity under controlled stress conditions (Ghanizadeh et al., 2016; Riazi et al., 2017), rate-of-adsorption (ROA) analysis (N_2, CO_2)

(Haghshenas et al., 2016); liquid (formation oil/brine) and relative (hydrocarbon liquid/gas) permeability and lastly combined scanning electron microscopy (SEM) and micro-wettability analysis (Deglint et al., 2017).

Examples

For the analyzed sample suite, porosity, permeability, modal pore size distribution and surface area increase constantly with sequential pyrolysis stages associated with release/generation of free light oil and fluid-like hydrocarbon residue (up to 380 °C; ESH Rock-Eval). The variability observed in different pyrolysis stages is attributed to the degree of (1) expulsion of free hydrocarbons from matrix, depending on OM content, (2) devolatilization of fluid-like hydrocarbon residue and 3) the possible occlusion of pore volume with residual carbon/liquid-oil phase as a result of solid bitumen degradation. Absolute (formation oil) permeability values are consistently, up to 50%, lower than the slip-corrected gas (N_2) permeability values - the differences between absolute and slip-corrected gas permeability values are larger for samples with lower permeability values. Laboratory results, augmented with numerical simulation studies, point to the technical viability of EOR techniques to improve oil recovery from the analyzed intervals within the Western Canadian tight oil and liquid-rich gas reservoirs.

Conclusions

There are currently major uncertainties associated with identifying an optimal development strategy for enhanced recovery applications in the Western Canadian tight hydrocarbon reservoirs. In this study, through the application of multiple advanced core/cuttings analysis techniques on diverse sample suites, fundamental controls on the EOR process in unconventional reservoirs are examined. The findings of this study could be beneficial to operators developing the Western Canadian tight oil resources by allowing them to identify/target specific zones within the reservoirs of interest with reservoir quality amenable to maximizing gas storage/transport during cyclic solvent injection for EOR applications.

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