geoconvention
Calgary • Canada • May 11-13 2026

Gas Injection Design to Co-optimize Incremental Oil Recovery and CO_2 Storage using a Multi-fractured Horizontal Well Completed in the Duvernay Formation

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Summary

Unconventional reservoirs (low-permeability tight and shale) host massive quantities of natural gas and liquid hydrocarbons, which are currently being developed with multi-fractured horizontal wells (MFHWs). Despite their widespread use, the recovery factor from MFHWs often remains below 10%. To access more of the trapped hydrocarbons, enhanced recovery methods such as the Huff-n-Puff (HNP) process are commonly employed.

In the HNP process, a suitable gas (e.g., CO_2) is injected for a pre-determined period ("huff"), allowed to soak into the reservoir, and then the well is produced back to surface ("puff"). Through various mechanisms, liquid hydrocarbon recovery is expected to increase relative to primary recovery. The HNP process is repeated through multiple cycles to sustain improved production over time.

Beyond improving recovery, MFHWs also present an opportunity for greenhouse gas (GHG) storage. With thousands of MFHWs drilled to date, the subsurface infrastructure is already in place to facilitate the injection of massive quantities of GHGs (e.g., CO_2) to simultaneously enable both enhanced hydrocarbon recovery and effective underground CO_2 storage.

An optimization framework using numerical simulation is introduced herein to investigate the feasibility of co-optimizing CO_2 HNP recovery and storage processes for MFHWs in the Trochu Sub-Basin of the Duvernay East Shale Basin.

Theory / Method / Workflow

A MFHW with a long production history was selected for simulating CO_2 HNP and storage. A detailed fluid model was constructed using various measured PVT experiments. Additional laboratory experiments, including measurements of matrix permeability over a range of stresses, and expected effective diffusion coefficients derived from published data, were incorporated into the modeling process.

Production data were history-matched using a comprehensive compositional numerical simulation model based on a quarter-fracture (element of symmetry) Local Dual Porosity, Dual Permeability (L-DP-DK) framework (Hamdi et al. 2023). This numerical model includes a limited DP-DK region near the primary hydraulic fracture, characterized by enhanced permeability and reduced fracture spacing, to provide an extended surface area for in-situ fluid mixing. The dimensions and properties of this region were determined through the history-matching process. Additionally, to ensure the model does not exaggerate future production performance, the history-matching process was further constrained by a long-term forecast from a single-porosity model.

The history-matched model was then employed to assess the 20-year performance of HNP using predetermined rates of 5 and 10 MMscf/D with fixed durations, such as 80/80 (i.e., 80 days of injection and 80 days of production without soaking) and 120/120, as proposed by the operator. Such fixed designs are not optimized to maximize the benefits from HNP recovery and storage. Therefore, an additional design, based on mathematical optimization of net present value (NPV), was performed to ensure maximum oil production and CO_2 storage during the long-term HNP process.

The risk of piloting CO_2 HNP and storage processes (for the operator) is that the incremental oil recovery is sometimes insufficient to cover the investment required to test the technology. In addition, these pilots require careful planning, significant capital investment, and are operationally disruptive. A solution is therefore required to mitigate the risk of piloting HNP with MFHWs, and to promote the evaluation of CO_2 sequestration. To address this, a new extended piloting process was proposed to provide early assessment of HNP performance and injectivity, followed by a more conventional multi-cycle CO_2 HNP phase.

In this proposed process, a single-cycle CO_2 HNP is conducted first to provide an initial estimate of CO_2 injectivity and storage. A multi-cycle CO_2 injection/falloff is also implemented using a procedure similar to Mavor et al. (2007). This step is used to evaluate changes in injectivity with cumulative injection and to provide an additional evaluation of CO_2 storage potential. Finally, a more conventional multi-cycle HNP is performed to evaluate incremental oil recovery and the permanence of injected CO_2 storage. This process was optimized using a multi-objective optimization framework (Hamdi et al. 2018) to achieve maximum oil recovery with minimal injectant while maximizing CO_2 storage.

Results, Observations, Conclusions

The results demonstrate that the history-matched L-DP-DK model avoids over-prediction and reproduces key production characteristics consistent with field observations, including the Eagle Ford Pilot D (Hoffman 2018). Simulation results indicate that CO_2 HNP performance is highly sensitive to injection rate, cycle duration, and diffusion behavior. For fixed-cycle designs, higher injection rates yielded substantially greater incremental oil recovery than lower rates, albeit with higher injected gas volumes.

Optimization of the 20-year HNP process using NPV criteria, including the recovery and storage credit, indicated that maximum injection rates, extended injection, soaking, and longer production periods, along with higher production bottomhole pressures, yielded the highest economic outcomes. **Fig. 1** demonstrates that under optimized conditions, the process achieved 50% additional incremental oil recovery (left) while securely storing over 80,000 tonnes of CO_2, approximately 16% of the injected CO_2 (right).

Further, simulation of the proposed extended piloting workflow confirmed its effectiveness for early injectivity and storage assessment. Multi-objective optimization of this workflow achieved 34% incremental oil recovery while storing 27% of injected CO_2 over a six-year period.

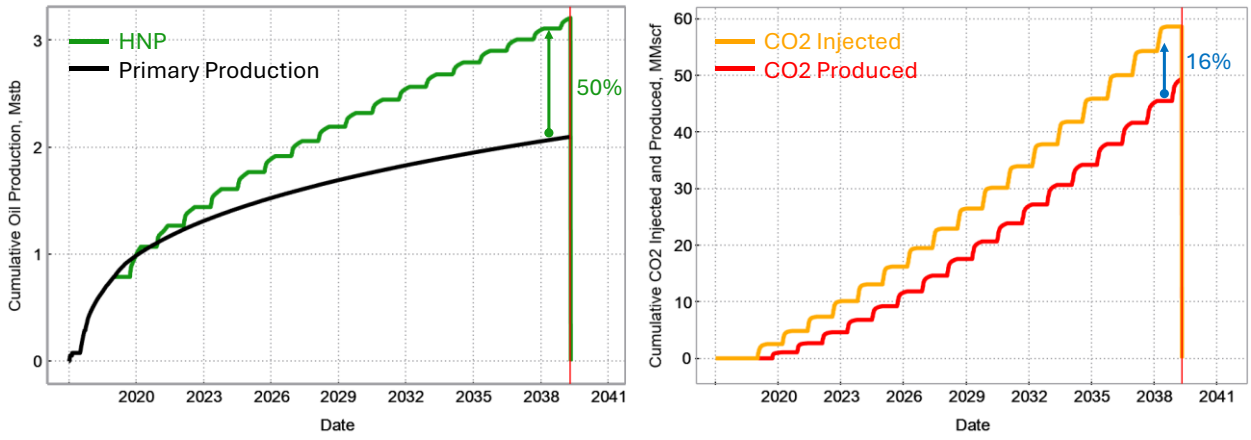


Fig. 1 – Simulated results from optimized HNP quarter-fracture model (element of symmetry) showing 50% incremental oil recovery and 16% CO_2 storage based on NPV optimization

Acknowledgements

The authors gratefully acknowledge Artis Exploration Ltd. for providing core, PVT, production, and other associated data that supported this study, and for granting permission to publish these results.

Hamidreza Hamdi would like to thank Rock Flow Dynamics Inc. for their support of his independent research. This paper has been made possible by the licensed use of the tNavigator Software developed by Rock Flow Dynamics.

Chris Clarkson gratefully acknowledges the sponsors of Tight Oil Consortium (TOC) and Transitional Energy Consortium (TEC) hosted at the University of Calgary. He would also like to thank ARC Resources and Ovintiv for support of his Research Chair in the field of Subsurface Transitional Energy Pathways ('STEPs') at the University of Calgary, and Matt and Tara Brister for support of his Tamaratt Professorship in Transitional Energy Research.

Partial funding for this research has been provided through a Natural Sciences and Engineering Research Council (NSERC) Alliance Grant (ALLRP 568627-21).

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