geoconvention
Virtual Event
September 21-23
2020
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# Using Compositional Simulations to Assess Huff-n-Puff (HnP) Performance for a Duvernay Shale Well

*Hamidreza Hamdi[1], Christopher R. Clarkson[1], Ali Esmail[2] and Mario Costa Sousa[1]*

*[1]University of Calgary*

*[2]Encana Corporation*

## Summary

Production from unconventional tight and shale oil reservoirs has become an economically viable option through utilization of multi-fractured horizontal well (MFHW) technology. With this technology, the contact area between the wellbore and the reservoir is increased, and the hydrocarbon production rate is markedly improved. Unfortunately, with the natural depletion process, only a small fraction of the original oil in place can be recovered and the majority of hydrocarbon in place remains within the reservoir. Therefore, operating companies and researchers are seeking technologies to recover additional oil in place using different recovery methods including gas injection techniques.

In this work, the feasibility of a cyclic gas injection method (i.e. huff-n-puff) for potential implementation in a Duvernay shale well is studied. Laboratory experiments and petrophysical measurements are used to create a set of reliable compositional simulation models that can match multiphase production data of a subject well using Bayesian history matching techniques. The results show that the propagation of uncertainty in the modelling can have a significant effect on designing an optimal gas injection scenario for this field case study. In addition, different numerical modelling choices are presented to evaluate the principal HnP recovery mechanisms from simulation results.

## Theory / Methods

Since successful operations were reported by EOG (Rassenfoss 2017), cyclic gas injection has attracted great interest among researchers as an efficient enhanced oil recovery technique in unconventional reservoirs (Wan 2013, Yu et al. 2014, Alfarge et al. 2017, Hamdi et al. 2018, Hamdi et al. 2019). With this technique, which is also known as huff-n-puff (HnP), hydrocarbon gases, $CO_2$, or inert gases (e.g. $N_2$) are injected into the reservoir at elevated pressures, and after a soaking period, the oil and gas are produced back from the same well. This process can be repeated multiple times until the incremental recovery in successive cycles is minimized. The efficiency of the HnP process strongly depends on the characteristics of the in-situ reservoir rock and fluid, the injectant type (i.e., lean or rich gas) and the imposed operating conditions. The HnP process should be designed accurately to augment the mass transfer between the oil and gas to enhance the oil production rate. This requires detailed laboratory experiments and accurate compositional simulations to optimize the HnP process and to maximize production.

Prior to running the HnP simulations, a series of laboratory experiments were conducted to measure the fluid properties accurately and to derive the pressure-dependent permeability curves under cyclic loading and unloading cycles (Hamdi et al. 2018). These experiments serve as critical inputs to construct a representative numerical model that can be used to history match primary production data as well as for forward simulation of the HnP process. However, this simulation workflow suffers from non-uniqueness in solutions. Different combinations of reservoir parameters and/or different modelling strategies can provide equally probable history matching models, whereas their HnP performance predictions could be considerably different. Therefore, it is essential to assess the uncertainty in the models to understand how different modelling strategies can impact an optimal HnP design. Bayesian history matching (Gamerman 1997) is a statistical process that can generate a set of models that can match the measured data. This set of models is used to optimize the HnP under uncertainty by maximizing the lower quantile of the oil recovery from the models after ten years of HnP production.

## Results, Observations, Conclusions

In this simulation study, Bayesian history matching provides the full joint probability distributions, which represent all the models that can reasonably match the measured production data. The results show that some fracture parameters such as the conductivity and fracture half-length, are among the most sensitive parameters, while some matrix variables such as molecular diffusion coefficients and matrix relative permeability data are fairly insensitive. This, however, does not mean that these sensitivity results can still hold for predicting future processes such as HnP. In particular, dispersion coefficients that have a minimal impact on the history matching results can have a substantial effect on HnP performance. Therefore, to ensure a successful HnP pilot design is achieved, the *risk in design* is also implemented in the HnP optimization process to account for the persistent uncertainty in the modelling. The optimization under uncertainty demonstrates that a *low-risk* cyclic rich-gas injection design can be achieved using the following parameters: a maximum injection rate of 5MMscf/day/well; a huff process of 20-70 days; a short soaking time of ~7 days; and a puff process, with a constant flowing bottomhole pressure around the saturation pressure (3500-4500 psi), that is maintained for around 50-120 days. With these designed parameters, the *low-risk* rich gas injection scenario can produce at least 30% additional recovery compared to a primary depletion scenario. An *optimistic* design can lead to a higher recovery (~70% additional recovery) compared to the primary depletion.

## Novel/Additive Information

In this study, the mechanisms of HnP oil recovery are investigated through a detailed Duvernay field case study. The importance of laboratory experiments in this integration study is highlighted. It is shown that a single history-matched model using production data cannot fully represent the uncertainty in predicting future processes such as cyclic gas injection. Various modelling strategies should be surveyed and the HnP design should account for the uncertainty in the models. This study provides a workflow and practical guidelines for an efficient implementation of an HnP process in unconventional reservoirs.

## Acknowledgments

Hamidreza Hamdi would like to thank Mitacs and Rock Flow Dynamics Inc. for supporting his postdoctoral fellowship. Chris Clarkson would like to acknowledge Encana and Shell for support of his Chair position in Unconventional Gas and Light Oil research at the University of Calgary, Department of Geoscience. The authors further gratefully thank the sponsors of the Tight Oil

Consortium, hosted at the University of Calgary, for their support. Partial support for this work was provided through an NSERC CRD grant (CRDPJ 505339 – 16) held by Clarkson.

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