geoconvention
Calgary • Canada • May 13-17 2019

Integrated Frac-through-Flowback Modeling to Estimate the Initial Conditions of Flowback: Example from the Montney Formation

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Summary

Quantitative analysis of flowback data from multi-fractured horizontal wells (MFHWs) using rate-transient analysis (RTA) methods has proven to be a fruitful approach to derive critical hydraulic fracture properties for use in development planning. However, due to the alteration of near-hydraulic fracture reservoir conditions (fluid saturation and pressure) caused by leakoff of fracturing fluids to the formation during the stimulation treatment and post-stimulation shut-in (when this occurs), the initial conditions on flowback are often unknown. Incorrect assumptions regarding the initial conditions of flowback can, in turn, lead to significant errors in derived fracture properties.

In this study, a method for evaluating the initial conditions of flowback is proposed by modeling fracturing fluid leakoff during the fracture stimulation and shut-in prior to flowback. A new semi-analytical model based on the dynamic drainage area (DDA) concept, coupled with a hydraulic fracture model, is used for this purpose. This new model, which assumes that the reservoir adjacent to the primary (propped) hydraulic fracture (PHF) can be represented with a dual-porosity enhanced fracture region (EFR), was applied to single-stage stimulation treatment data of a MFHW completed in a low-permeability oil reservoir within the Montney Formation. The results of the modeling demonstrate that the fluid pressures and frac fluid saturation within the EFR adjacent to the PHF are significantly elevated above virgin reservoir conditions. These initial conditions were then used to constrain history-matching of the flowback data using the new dual-porosity DDA model. Additional constraints were applied to the modeling by using laboratory-measured propped and unpropped fracture and matrix permeability as a function of stress.

Theory / Method / Workflow

In previous work (Clarkson et al. 2016), a semi-analytical model based on the DDA concept was used to history-match flowback data from the studied Montney MFHW. This early-version DDA model, which assumed a single-porosity reservoir, was then used to simulate frac fluid leakoff during the hydraulic fracture treatment and subsequent shut-in by Clarkson et al. (2017) to estimate the initial fluid pressure and saturation in the reservoir prior to flowback. However, this model was not fully integrated with a hydraulic fracture model (although it was constrained by the PHF propagation during the stimulation treatment), and assumed a single-porosity reservoir adjacent to the PHF, which limited the amount of fluid pressure and saturation elevation observed. Finally, the model could not predict the PHF pressure changes during shut-in. In subsequent work by Zhang et al. (2018), these limitations were removed by 1) introducing a new dual-porosity version of the DDA leakoff and flowback model (DP-DDA) 2) fully integrating the DP-DDA model with a PHF fracture model assuming a PKN geometry and 3) allowing the PHF fluid pressure to be predicted during shut-in. The latter update enables pressure prediction at the beginning of flowback, providing a valuable constraint on quantitative flowback rate-transient analysis. In more recent work, a proppant transport model was added to the hydraulic fracture model to allow the propped fracture (PHF) length to be estimated, which is an important initial constraint on flowback modeling. The new fully-integrated frac/leakoff model was then re-applied to the same well studied by Clarkson et al. (2016, 2017) in order to re-evaluate the initial conditions of flowback.

Results, Observations, Conclusions

For the studied Montney reservoir, the initial (virgin) reservoir pressure is estimated to be ~ 3700 psia. Using the new integrated modeling approach, the fluid pressures at the start of flowback within the PHF, EFR fracture network and matrix investigated areas were estimated to be 5049, 5045, and 4979 psia, respectively. Further, water saturation within the EFR was determined to be significantly elevated above the initial formation value. This result indicates that the assumption of virgin reservoir conditions on flowback is in significant error and could adversely impact the evaluation of hydraulic fracture properties using flowback modeling. The result further validates the concept of “breakthrough” pressure, used by the authors in previous flowback analytical modeling attempts, which suggested that formation fluids breakthrough to the fracture during flowback at formation pressures elevated above pre-stimulation conditions.

Utilizing these initial conditions, laboratory-derived estimates of stress-dependent fracture and matrix properties, laboratory-derived rock mechanical properties, and an initial estimate of propped fracture half-length from the frac modeling, the flowback data from the subject MFHW were successfully history-matched using the new DP-DDA flowback model. The fracture parameters derived from the matching were gained with greater confidence than previously because of the number of constraints applied to the modeling.

Novel/Additive Information

Previous attempts by various authors to analyze flowback data using RTA methods or simulation have commonly assumed initial (virgin) conditions (pre-stimulation) for the reservoir. The current study has demonstrated, using a rigorous integrated modeling approach, that the conditions in the reservoir (pressure and saturation) adjacent to the primary (propped) hydraulic fracture can be significantly different than virgin conditions. These differences in assumed initial conditions can lead to errors in fracture property estimates from flowback analysis that have not been previously considered until now.

Acknowledgements

The authors gratefully thank the sponsors of the Tight Oil Consortium hosted at the University of Calgary. Chris Clarkson would like to acknowledge Shell, Encana, and Alberta Innovates for support of his Chair position in Unconventional Gas and Light Oil at the University of Calgary, Department of Geoscience. Funding for this study was provided by an NSERC Collaborative Research and Development Grant (CRDPJ 501135–16) to Clarkson. The authors would like to thank Dr. Hamidreza Hamdi for the valuable discussion on the implementation of laboratory data and reference hydraulic fracture models.

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