# Multi-Well RTA in Unconventional Wells with Non-Uniform Microseismicity-constrained SRVs

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## Summary

An analytical technique is introduced to model multifrac horizontal wells in unconventional reservoirs. The model formulation enables defining a non-uniform Stimulated Reservoir Volume (SRV), where the Enhanced Fracture Regions (EFRs) are constructed using a hybrid approach that integrates microseismic and production data analysis.

## Theory

Completion evaluation and production forecasting via integration of Rate Transient Analysis (RTA) models[1-3] and microseismic interpretations[4] are anticipated to be a highly lucrative field owing to the rise in the usage of hydraulic fracturing in the completion of unconventional wells. In order to facilitate the adoption of microseismic monitoring in dynamic reservoir modeling studies and extend the standard use of the technology in fracture characterization, it is essential to implement flexible models that are capable of characterizing and dealing with heterogenous SRVs. This work starts with applying a hybrid workflow to combine Four Straight-Line (4SL) techniques to process microseismic and production data and extract the spatial structure of SRV in a well-pad targeted an ultra-low permeability formation. A 3D physics-based RTA model, called Nine-Grain (9G) model[5], is then utilized to construct a multi-well reservoir structure, allowing the definition of non-uniformly distributed stimulated rock volumes and making production forecasts analytically. The model sub-divides the reservoir into nine linear flow regions, and the EFRs can be either identical or non-uniform in width and permeability assigned by 4SL. The effect of variable productivity (frac-hit-induced or Geomechanical) is also incorporated into the model by adjusting the definitions of pseudo-pressure and pseudo-time and using the superposition theory.

## Analytical Modeling

The 4SL entails coupling of flowing material balance, linear flow analysis, and Dynamic Parameter Analysis (DPA) to achieve the SRV dimensions. The first two methods are routinely applied in RTA, and the DPA plots are utilized to cluster microseismic events and then sort them based on the level of inelastic deformation. In particular, RTA is applied in order to choose the most probable candidates, ranked by DPA, for contributing to the well productivity. The 4SL-derived SRV of the case study and its adjacent wells are depicted in **Fig.1**, where the green cuboids represent EFRs, and the circles denote the selected microseismic clusters that are associated with high-plasticity and most likely shape the conductive fracture network. Notably, applying 4SL enables having a realistic representation of the SRV and contributes to resolving the non-uniqueness of the solution as the main deficiency of the stand-alone RTA. **Fig.2** shows the production forecasts made by the history-matched 9G models in two single- and multi-well reservoir structures. In the multi-well analysis, the SRV structure of adjacent wells is used to refine the drainage volume boundaries of the case study. Besides obtaining more accurate production forecasts, by applying 4SL-9G both completion efficiency and effective well length are automatically evaluated, the infill wells can be planned with a broad knowledge regarding the distribution of the existing fracture network, and the well spacing optimization can be accomplished more reliably. **Fig.3** depicts a snapshot of the 4SL SRV modeler.

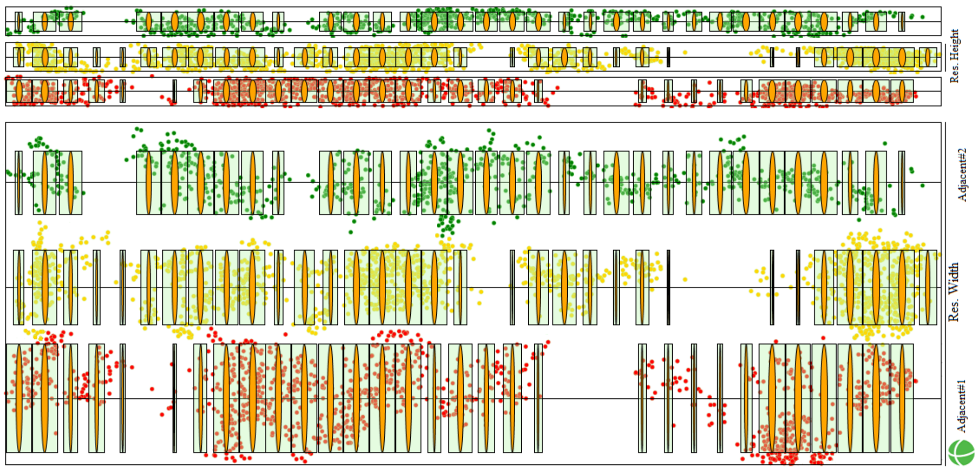


**Fig.1 Top and cross-sectional views of the multi-well analytical RTA model constructed for the case study. 4SL combines RTA with DPA to find regions with significant inelastic deformations, define EFRs and refine drainage volume boundaries.**

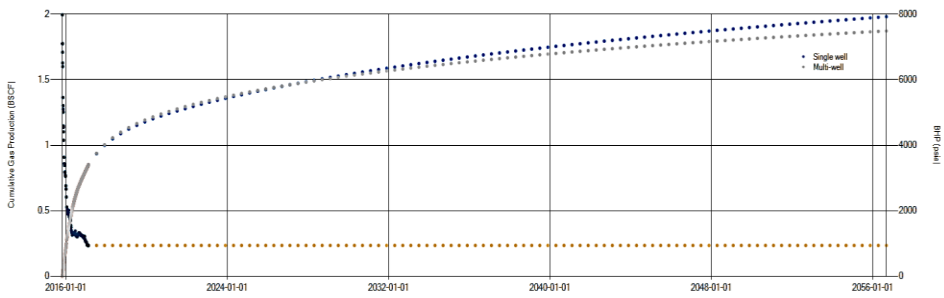


**Fig.2 Production forecasts made by two single-well and multi-well non-uniform 9G models. Despite reproducing the production history, when using the single-well model, the EUR is overestimated.**

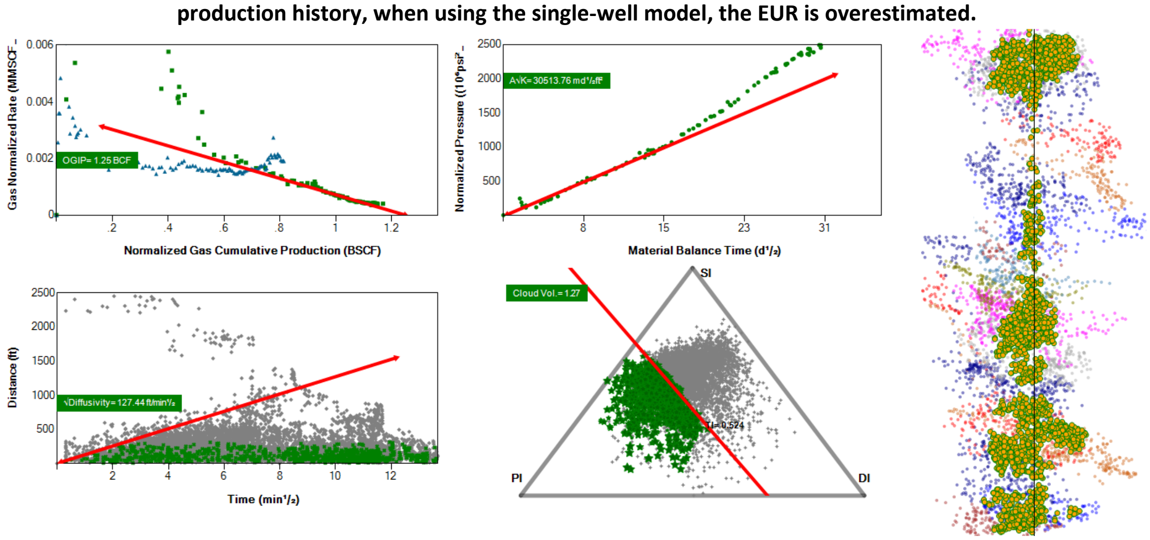


**Fig.3 Snapshot of how 4SL uses four straight-line techniques to extract volumetric and geometrical information on the SRV. SL1: Flowing Material Balance, SL2: Linear Flow Plot, SL3: Diffusion Plot, SL4: DPA Plot. The figure on the right denotes the centroids of DPA clusters, where the yellow circles are selected by 4SL as the SRV indicators.**

## Well Spacing Optimization

In this case study, integrating RTA and microseismic analysis to characterize the SRV not only reduces the uncertainty associated with the reservoir modeling parameters but also enables conducting a simple, integrated well spacing optimization. To demonstrate the practicality of 4SL-9G in determining the optimum number of wells per section, here we construct three single-well models and conduct a sensitivity analysis on the effect of reservoir width on the well and section cumulative gas productions after 15 years at BHP=1000 psi; Case#1 is defined solely based on the production data analysis of the well (flowing material balance and linear flow analysis), while the two other cases are generated by 4SL in two uniform and non-uniform formats, **Fig.4**. As depicted in **Fig.5**, by reducing the well spacing, the cumulative production from the section increases monotonically, however, after adding a certain number of wells there is a reduction in the production of individual wells. Case#2 and Case#3 result in an optimum well spacing of about 500 ft, while the first case (stand-alone RTA) behaves differently and is off the expected trend sourced from its uncertain fracture dimensions. Although the results of both 9G models are comparable, generally, using the non-uniform model allows for adjusting the matrix permeability more accurately, which in turn, affects the long-term reservoir behavior. The outcome of such analyses can feed economic studies involving cashflow to optimize the field development plans.

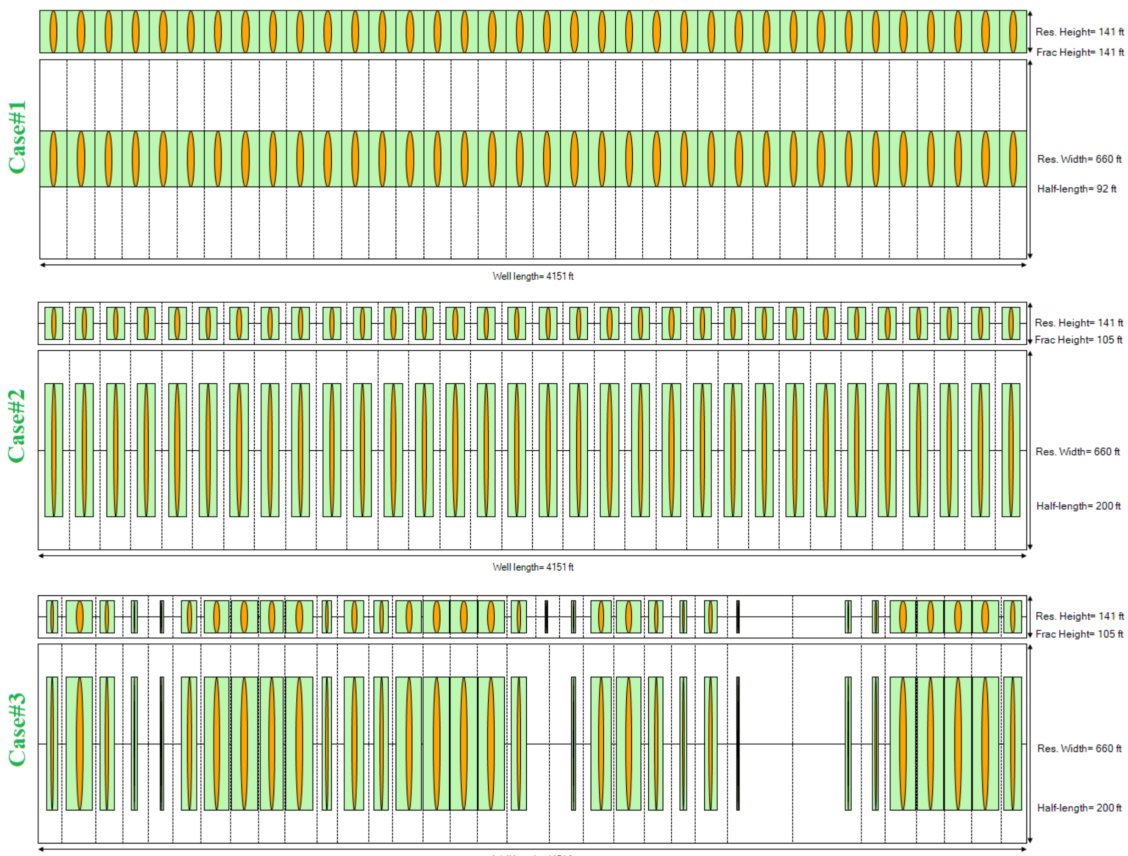


**Fig.4 Schematics of the single-well models constructed to analyze the effect of well spacing on EUR. Case#1 (five-region) is built based on the routine RTA analysis, while Case#2 and Case#3 are extracted applying the 4SL. Notably, Case#2 is similar to Case#3 except for its EFR locations which are uniformly distributed through the SRV.**

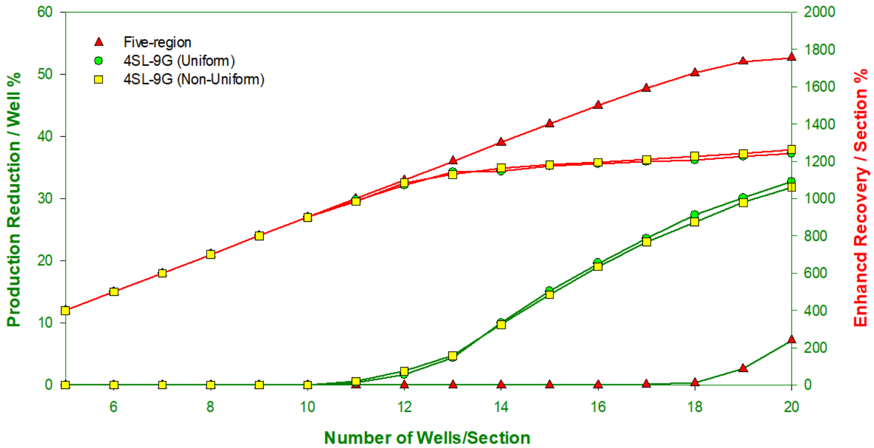


**Fig.5 Both uniform and non-uniform 4SL-derived 9G models result in an optimum well spacing of about 500 ft, while the full net-pay model overestimates the number of wells per section as its SRV dimensions are uncertain and show less sensitivity to the reservoir parameters.**

## Numerical Simulations

The final adjusted models are then exported in grid-based formats to be used for numerical analysis, **Fig.6**. When compared to analytical modeling, the numerical models incorporate saturation functions and variable fluid properties and can provide valuable information regarding the pressure and multi-phase saturation maps through the reservoir, hence, allow to make better estimations and infills plans.

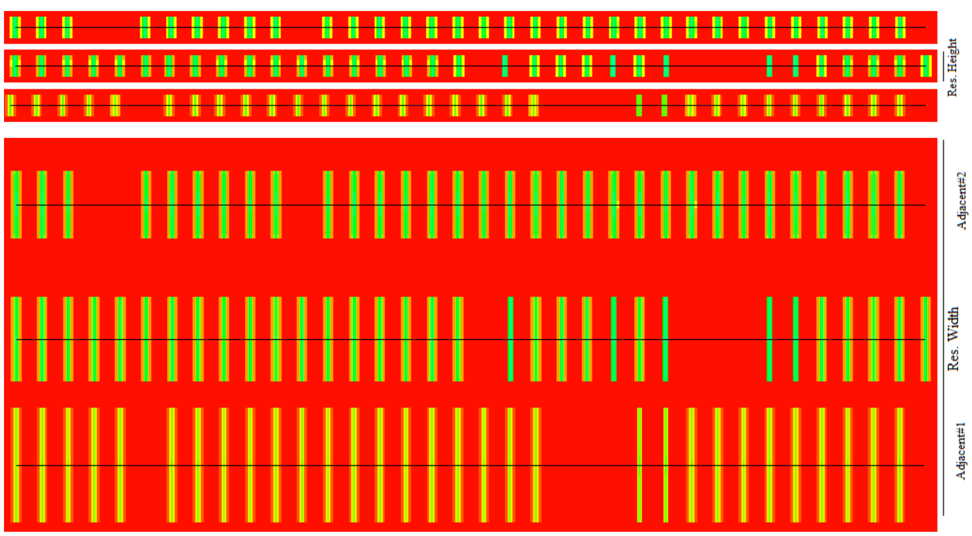


**Fig.6 Pressure distribution profile after 1-month gas condensate production. The analytically adjusted model parameters are used to initialize numerical multi-well models and provide pressure and multi-phase saturation maps over time.**

Applying the concave hall algorithm, it is also feasible to extract the refined SRV structure as a combination of high-perm enhanced fracture clouds, **Fig.7**, and investigate the fracture overlaps creating subsurface communication. When there is fracture interference between two adjacent wells, symmetric multi-well and/or multi-layer models, generated based on the findings of single-well analysis and using identical fracture lengths and heights for each well, are not sufficient to study the depletion pattern. In such cases, by combining DPA and RTA (4SL) a more sophisticated SRV model can be constructed to be used for numerical simulations, where the EFRs are fully constrained to the DPA clouds and can be either evenly or unevenly distributed through the SRV, **Fig.8**.

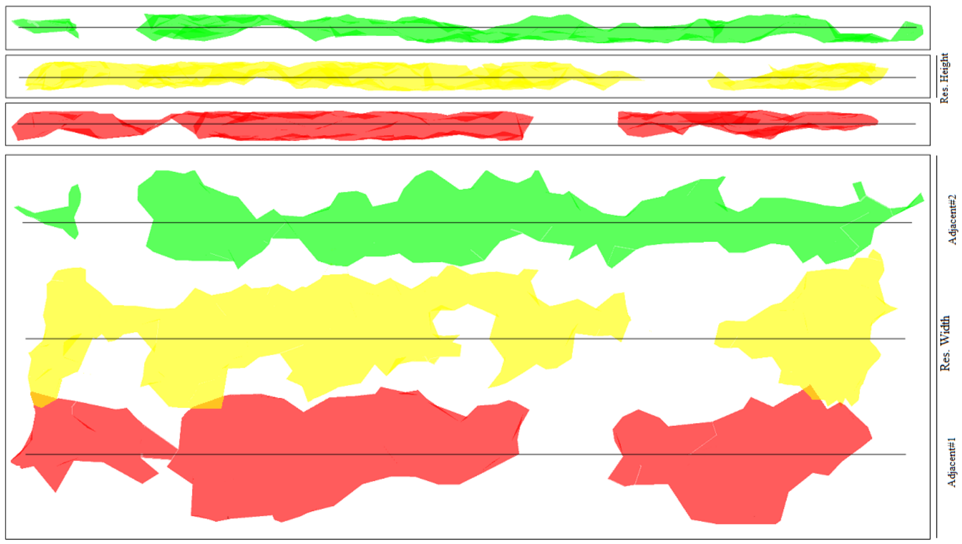


**Fig.7 Top and cross-sectional views of the refined SRV clouds constructed for the case study. The 4SL-extracted enhanced fracture clouds contain minimal simplifying assumptions regarding the SRV geometry.**

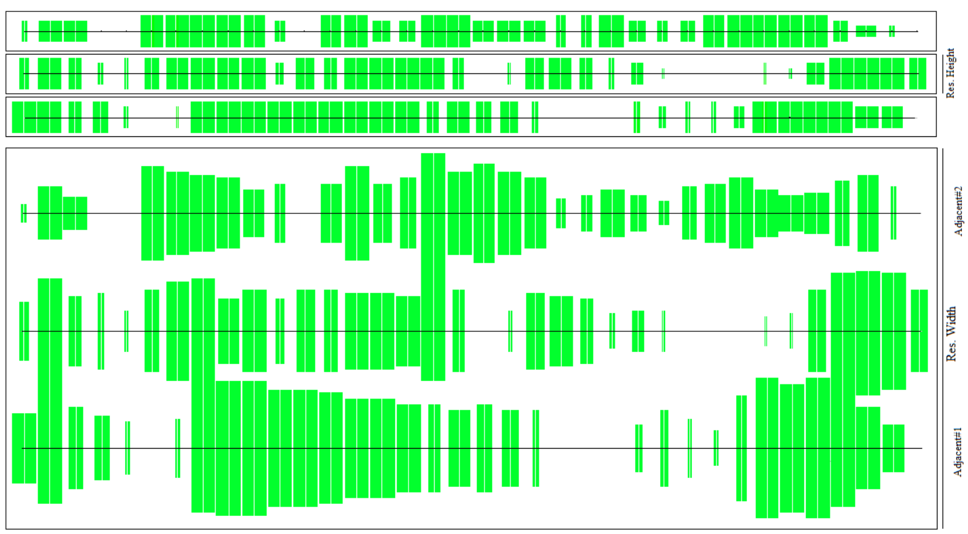


**Fig.8 Top and cross-sectional views of the numerical reservoir model with connecting EFRs constructed for the case study. Using such models enables studying the effect of fracture interference on the depletion pattern and well productivities.**

## Conclusions

The case study reviewed here demonstrated the practicality of a simple, reliable, and integrated algorithm in combining RTA and microseismic analysis to construct the SRV and reduce the uncertainty of completion and reserve evaluations in multifrac horizontal wells. Notably, the utilized 4SL technique to manipulate microseismicity-constrained EFRs propels the use of the 9G RTA model to aid production data analysis in unconventional reservoirs. The modeling outcome can then be used in large-scale numerical analysis.

## References

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