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Sensitivity study and Assisted History Matching in a shale gas reservoir

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Abstract

The invention of horizontal drilling and hydraulic fracturing technologies enabled economical production from unconventional plays, including shale gas reservoirs. Unconventional reservoirs have been in development in different parts of the world, but mostly in North American region for a long time. However, drivers for well performance, completion effectiveness and physics of fluid flow, in general, are still poorly understood. This is possibly due to the fact of the fluid flow in unconventionals being affected by a range of phenomena such as non-Darcy flow behaviour, gas adsorption/desorption, stress-dependence of rock properties and fracture properties such as half-length and conductivity. Additionally, even if physics of these processes can be deciphered, there is still a need for a large amount of costly data for accurate and complete reservoir characterization.

Historically, History Matching has been one of the most widely used and pragmatic options for sound reservoir management. Although, as discussed, there is a non-uniqueness and a lot of uncertainty in history matching process, it is still a viable and effective approach for reliable reservoir forecasting and development in unconventional reservoirs. In this work, we firstly developed a range of numerical models to model possible fracture distribution scenarios for a shale gas reservoir. Consequently, the performance of each built reservoir model compared against the historical data. Finally, sensitivity analysis and assisted history matching workflow have been applied to a model with the best historical data match, to further fine tune the model, with the aim of having the most reliable predictive model for a shale gas reservoir.

Introduction

Adoption of advanced technologies such as horizontal drilling and multiple stage hydraulic fracturing have been enabled the unconventional boom. Although, there have been a lot of activity in unconventional plays, resulting in drilling of many wells and development of a wide range of reservoirs, the fluid flow process itself and key drivers behind production performance in unconventional reservoirs have not been completely understood. During hydraulic fracturing treatment complex fracture networks are often generated, and the interaction of hydraulic fractures and natural fractures significantly impacts the complexity, which is an important contributor to ultimate gas recovery (Daniels et al., 2007; Maxwell, et al., 2013). Mayerhofer et al. (2008) have established that the well performance in unconventionals is a strong function of kh (permeability thickness), initial reservoir pressure, total hydraulic fracture, and fracture conductivity distribution. However, even in presence of microseismic data, actual fracture geometry and fracture conductivity distribution characterization is still a challenging endeavour, since microseismic data do not provide enough details about hydraulic fracture structure, total fracture area, and proppant distribution (Cipolla et al., 2012). History matching with field production data may provide an effective way to predict fracture properties. There have been quite a few studies in this space. Cheng

(2008) established a workflow for probabilistic assisted history matching using genetic algorithm and demonstrated this workflow successfully in Tengiz field. Yin et al. (2011) used Genetic Algorithm to calibrate static parameters such as fracture conductivity, fracture half length, matrix permeability and geo-mechanical /compaction parameters to match the dynamic data from shale gas wells.

In this study, first, 2 prior reservoir models have been built for a shale gas reservoir produced by a single horizontal well. Having compared the performance of each prior model against the historical production data, the most representative (in terms of historical production data match) reservoir model has been chosen for a detailed sensitivity and assisted history matching study. As an outcome of the study, we have established the key parameters contributing to the gas production and produced a range of calibrated posterior reservoir models, that can be used to generate a set of production performance predictions and represent the uncertainty.

Methods

The overall workflow for the study is comprised of the following components:

- Reservoir modeling: modeling of rock, fluid, rock-fluid properties, reservoir geometry and reservoir initiliazation
- Well modeling: horizontal well and completion modeling
- Fracture modeling: modeling of 2 fracture distribution scenarios
- Sensitivity analysis: sensitivity analysis for the model that has the best match for historical data
- History matching: history matching of the most representative (in terms of match to historical flow data) model against historical flow data

Reservoir modeling

In this work shale gas reservoir with a single well is modeled via dual permeability model using GEM simulator in CMG. Firstly, the **reservoir geometry and rock properties** data should be specified. Table 1 in appendix summarizes the variables and their values used to describe reservoir geometry and rock properties.

Next, **reservoir fluid description** data should be specified. Peng-Robinson equation of state is assumed to govern the PVT relation in shale gas system. The reservoir is assumed to consist of only CH_4 (methane gas) and reservoir temperature is set to 100 F. All properties of methane such as critical pressure, temperature, compressibility etc are calculated based on 100 F reference temperature.

Having specified rock and fluid parameters, relative permeability data should be entered to model the rock fluid interaction. **Relative permeability model** input parameters and their values are shown in Appendix (Table 2).

Once, reservoir geometry, rock and fluid properties and the data required to model their interaction have been specified, the reservoir needs to be **initialized**. Reservoir is assumed to be made of water and gas and initialized using gravity-capillary equilibrium method. Table 3 summarizes the values for reference pressure, depth and fluid contact depth.

Well modeling

Having specified all the required reservoir data and initializing the model, the **wells data** needs to be specified. In this study, the reservoir will be produced by one horizontal well. Well data is summarized in Table 4. 2D and 3D views of the reservoir model are shown in Figure 1 and Figure 2 below:

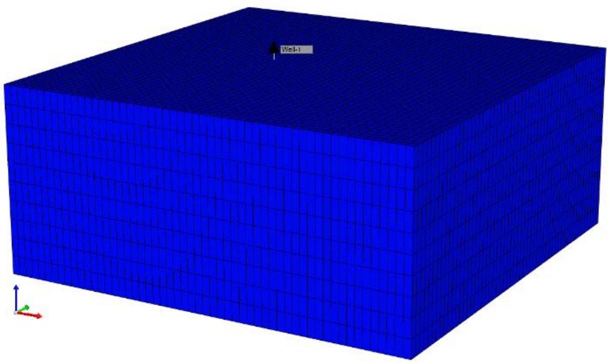

Figure 1. 3D view of reservoir model

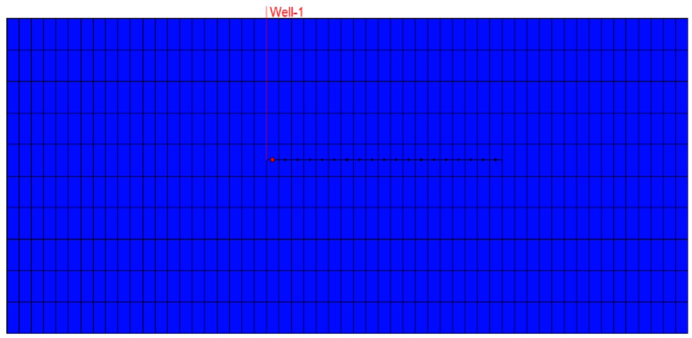

Figure 2. 2D cross section of reservoir model

Fracture modeling

Two different scenarios are used to model the fracture distribution for the shale gas reservoir. In the first scenario, four vertical equally spaced and equally sized planar fractures are used as a possible fracture distribution scenario in the horizontal section of well within the shale gas reservoir (Figure 3). Fracture properties for that scenario are summarized in Table 5 in Appendix.

For the second scenario, ten planar fractures with the equal spacing and width but different lengths are used (Figure 4)

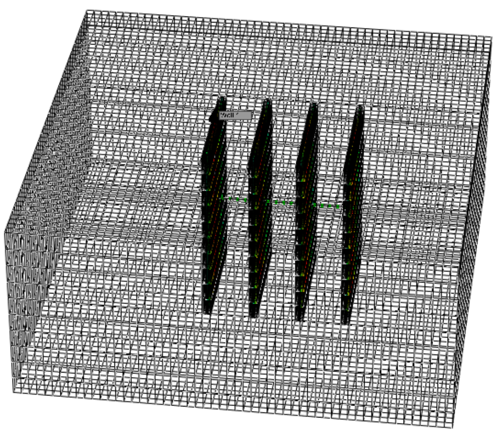

Figure 3. 3D view of fracture distribution for the 1st scenario

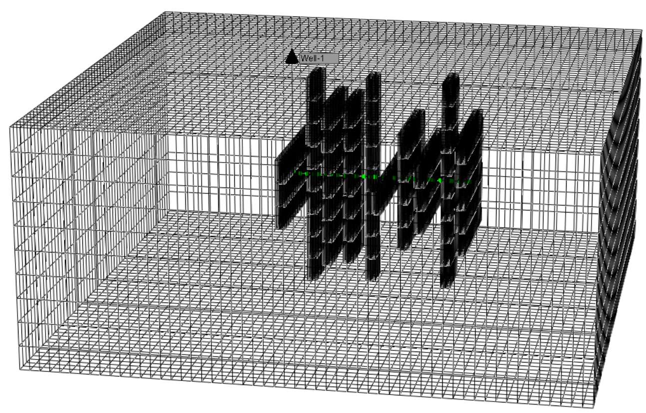

Figure 4. 3D view of fracture distribution for the 2nd scenario

It is a known fact that, although planar fractures are easier to parametrize and set-up, in reality, the fractures have more complex geometry. However, due to absence of microseismic data, no scenario with complex fracture network was generated.

Sensitivity analysis

Main goals of sensitivity analysis study are to determine 1) which parameters have an effect on the results 2) how much of an effect, parameters have on the results. In this study, sensitivity analysis has been applied to a model with the best historical data match (the model with 10 planar fractures), with the aim to identify the parameters that are the most sensitive to production, and further fine tune the model to get even better history matched model for reliable production forecasting. Parameters used for sensitivity analysis study are: horizontal and vertical matrix and fracture permeabilities, matrix porosity, fracture half-length, fracture permeability, fracture height, relative permeability constants and formation compressibility. Variation of +/- 25% is used to represent the uncertainty for each parameter. Both 1) one parameter at a time and 2) response surface methodologies (multiple parameters) are applied to understand the independent and combined effects of parameters on the reservoir performance.

History Matching

The importance and necessity of history matching in the context of reservoir development and including unconventional reservoir development have been discussed in abstract and introduction sections. The main components of history matching workflow are selection of 1) parameters to adjust 2) range and distribution of values for the selected parameters to sample from and 3) objective function(s) to match against. In this study, CMOST plugin within the CMG simulator is used to search for the best combination of parameter values that will give the lowest history match error. The parameters and their possible range of values to sample from have been selected based on the outcome of the sensitivity study. Equally weighted discrepancy between historical and simulated gas production and bottom hole pressures were used as an objective function to minimize to achieve a history match.

Results and Discussion

Firstly, a reservoir model without any fractures was developed and compared against the historical flow data to assess the viability of the base model. Fig 5 and Fig 6 show respectively the plots of simulated and field gas production and bottomhole pressure data:

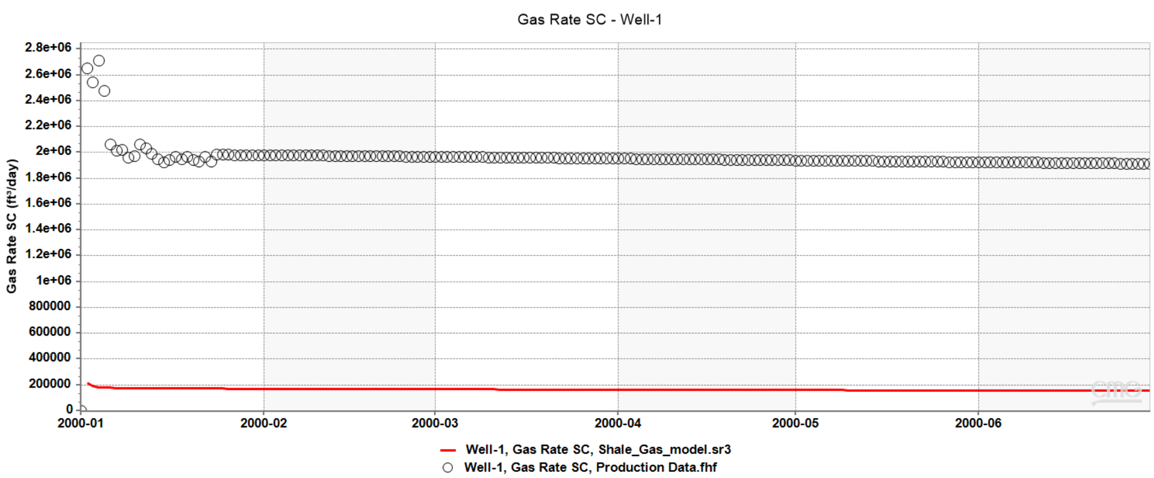

Figure 5. Simulated and observed gas production rates for well 1, base case

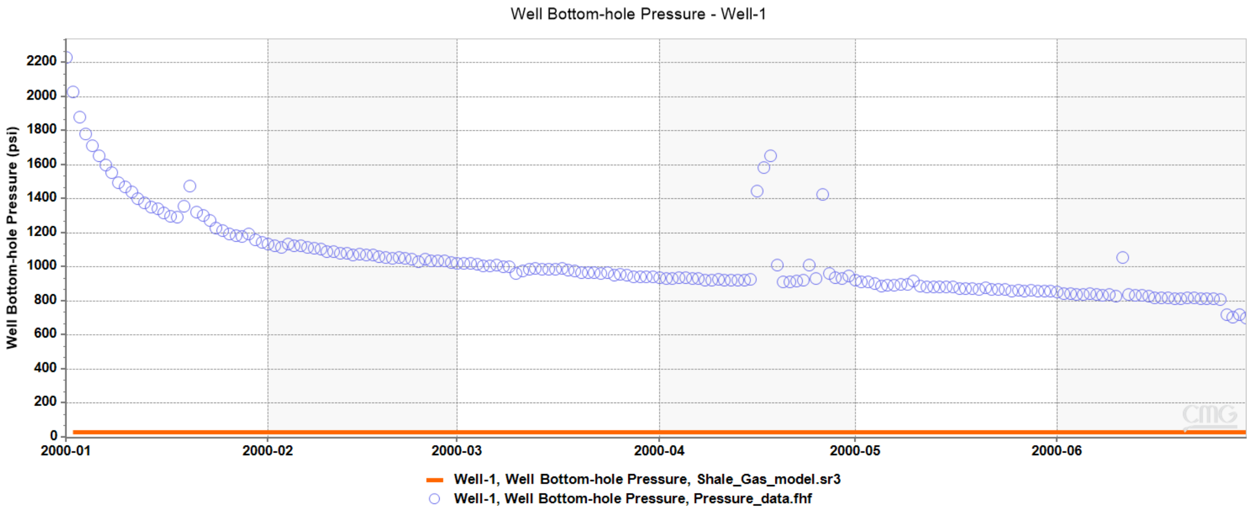

Figure 6. Simulated and observed well bottomhole pressure data for well 1, base case

As it is evident from Fig 5 and 6, base model without fractures cannot reconstruct the field data. Therefore, as a 2nd scenario, a model with four planar fractures (shown in Fig 4) have been developed. Fig 7 and 8 show respectively the plots of simulated and field gas production and bottomhole pressure data that case:

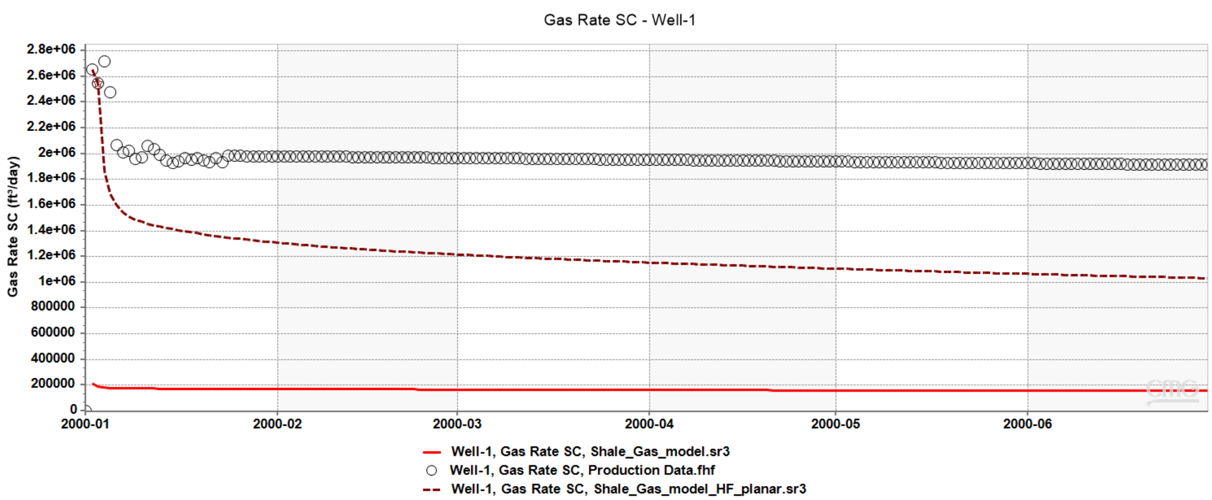

Figure 7. Simulated and observed gas production rates for well 1, base case and 1st scenario with 4 planar fractures

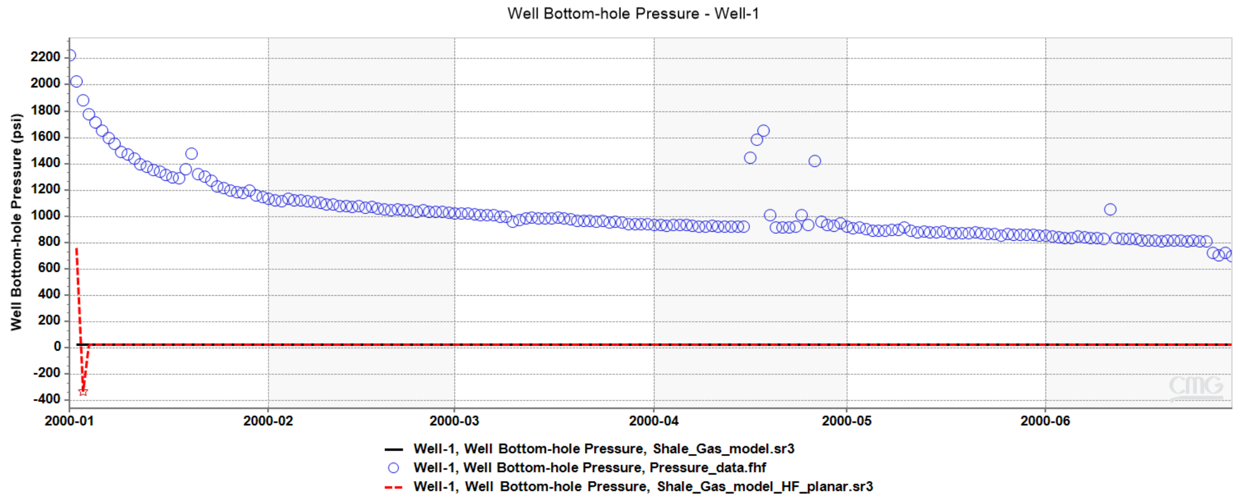

Figure 8. Simulated and observed well bottomhole pressure data for well 1, base case and 1st scenario with 4 planar fractures

Based on above two figures, we still observe large discrepancy between simulated and observed values at the field. To further improve the model, a model with ten planar fractures with the equal spacing and width but different lengths has been developed. Plots of simulated and field gas production and bottom hole pressure data are shown in Figure 9 and 10.

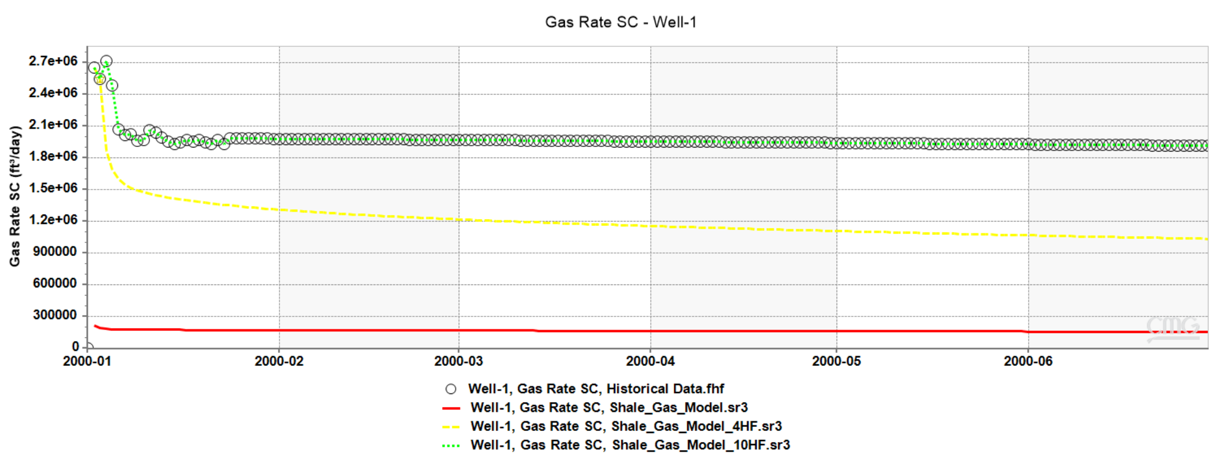

Figure 9. Simulated and observed gas production rates for well 1, base case. 1st scenario with 4 planar fractures and 2nd scenario with 10 planar fractures

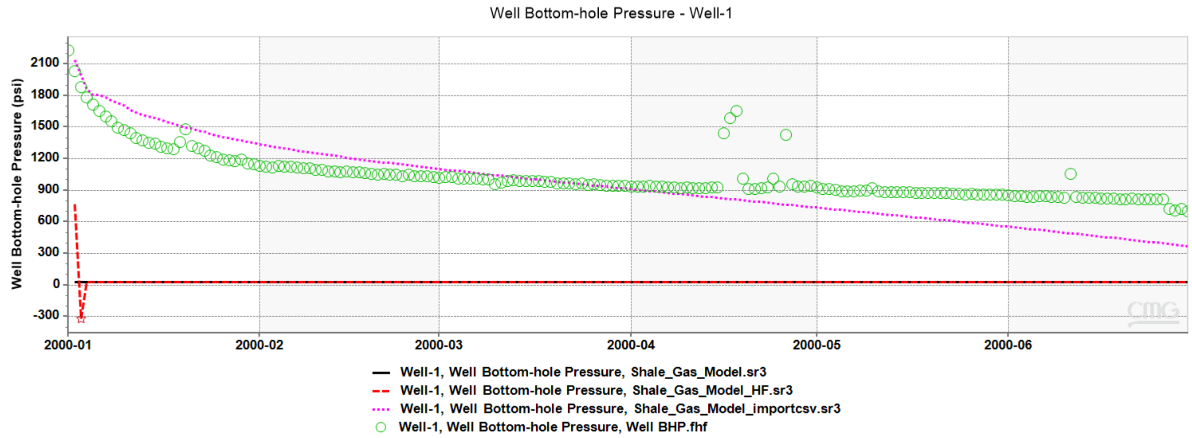

Figure 10. Simulated and observed well bottomhole pressure data for well 1, base case. 1st scenario with 4 planar fractures and 2nd scenario with 10 planar fractures

Based on above two plots, we observe that the scenario with 10 planar fractures produces much better matches in terms of both gas rate and bottomhole pressure. To further improve the quality of match and consequently, the predictive power of the reservoir model, we perform sensitivity analysis and history matching with this model. Sensitivity analysis with a set of selected parameters, described in methods section, has been performed for this case. Figures 11 and 12 show the multivariate and single variate effect estimates of selected variables on gas production and bottomhole pressure.

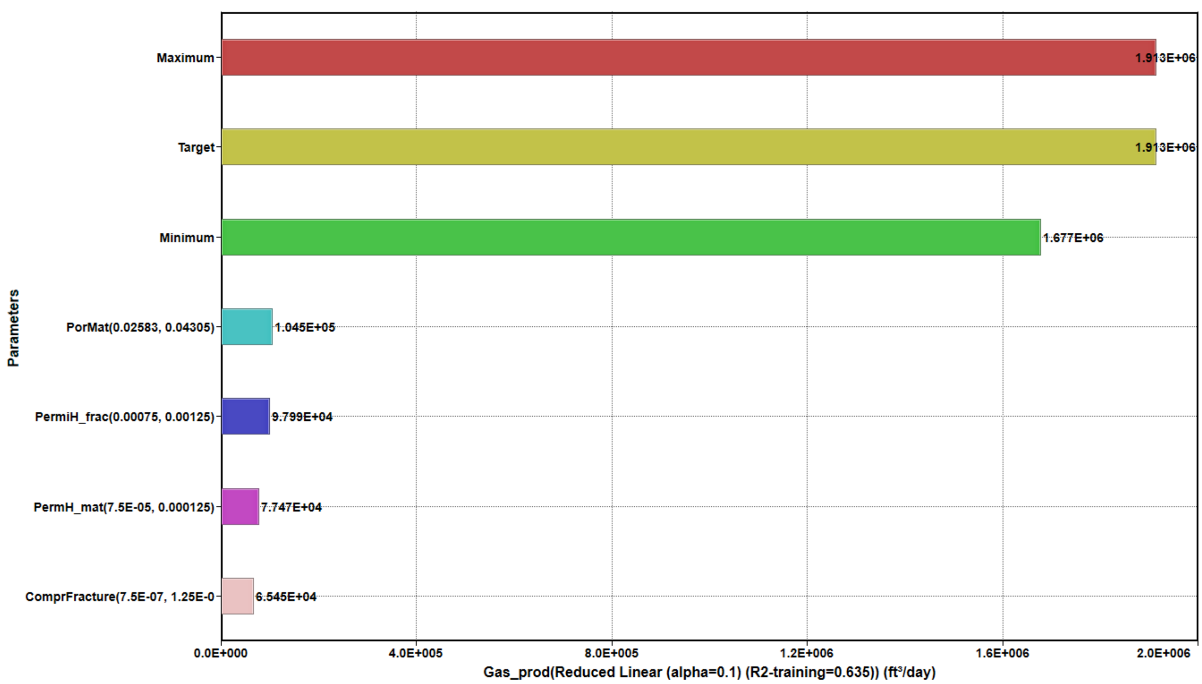

Figure 11. Sensitivity analysis outcome for gas production rate

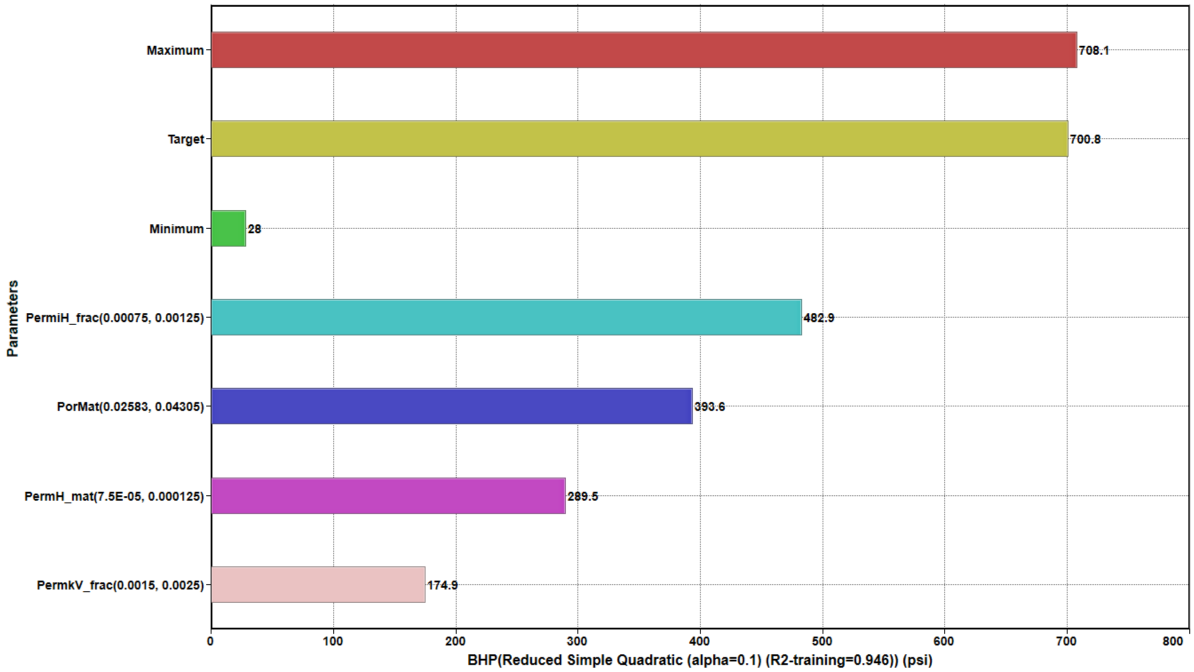

Figure 12. Sensitivity analysis outcome for bottomhole pressure data

Having identified the most sensitive parameters to production performance data, the history matching workflow, as described in the methods section, has been applied to a scenario with 10 fractures. Figures 13 and 14 show the quality of match for all the solutions for gas rate and bottom hole pressures, including the base and optimal cases.

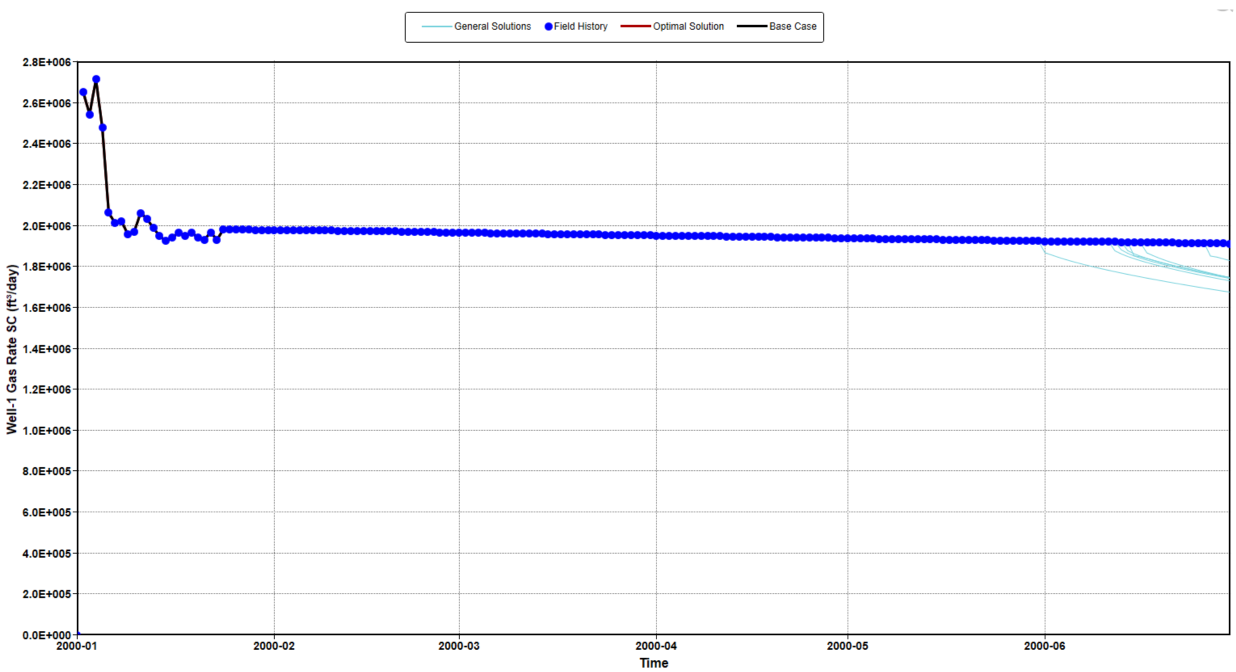

Figure 13. History matching realizations for the gas production rate

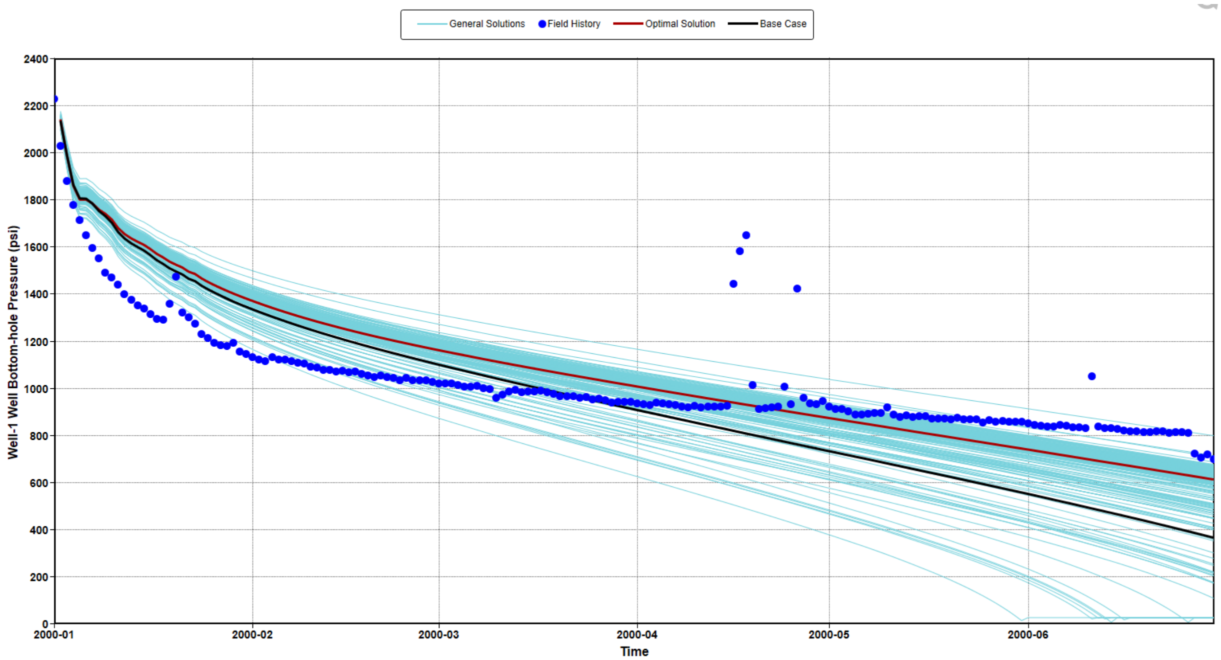

Figure 14. History matching realizations for the well bottomhole pressure

We have almost perfect math for the gas production rate, but not quite a perfect one for bottomhole pressure as evident from above 2 plots. To further increase the quality of match we can do one or combination of the following:

- Built a new fracture model, possibly with different number of fracture or more complex fracture network
- Select different or more reservoir and fracture parameters with possibly larger range of values to sample from
- Run history matching algorithm for large number of cases with different optimization algorithms/approaches

Conclusion

In this study, a structured workflow for reservoir, well, fracture modeling, sensitivity analysis and history matching for a shale gas reservoir has been presented. Each step within the workflow has been described, parameter values used, and outcomes of modeling and simulations has been presented. Potential causes for certain type of behaviours have been discussed and potential improvements to the workflow have been outlined.

References

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Appendix

Table 1. Parameters and their values for reservoir geometry and rock properties

Grid type, number, size of each grid	Cartesian, 55x55x10, 50 ft x 50 ft x 30 ft
Units	field
Matrix porosity	0.0344
Fracture porosity	0.001
Fracture spacing: x, y, z directions	50 ft x 0 ft x30 ft
Matrix permeability: x, y, z directions	0.0001 md, 0.0001 md, 0.00001 md
Fracture permeability: x, y, z direction	0.001 md, 0.001 md, 0.002 md
Rock compressibility	$10^{-6}\ 1/psi$

Table 2. Relative permeability model input parameters and their values

SWCON	0.2
SWCRIT	0.2
SOIRW	0.2
SORW	0.2
SOIRG	0.05
SORG	0.05
SGCON	0.05
SGCRIT	0.05
KROCW	0.8
KRWIRO	0.8
KRGCL	0.8
Exponent for Krw	2.0
Exponent for Krow	2.0
Exponent for Krog	2.0
Exponent for Krgcl	2.0

Table 3. Reservoir initiliazation data

Reference pressure	2500 psi
Depth	1050 ft
Water-gas contact	1500 ft

Table 4. Well data

Well type	Horizontal
Penetration/completion length	200 ft (horizontal section)
Well radius	0.25 ft

Table 5. Fracture properties

Fracture width	0.001 ft
Fracture permeability	10000 md
Orientation	Y axis
Number of refinements in x, y, z directions	7, 7, 1
Fracture half length	350 ft
Fracture height	150 ft
Fracture depth	180 ft