Modeling of Horizontal Wells in Unconventional Reservoirs

The use of horizontal wells and hydraulic fracture completion practices has become the norm today in unconventional resources. These wells and their completions present unique challenges to optimizing well and pad performance. Where to drill wells is generally not the issue. The primary decisions are:

- *number of wells per unit,*
- *vertical and horizontal placement of the wells in the formation,*
- *number, type and size of the hydraulic fracture stages,*
- *sequence of fracture treatments in pad completions, and*
- *placement of infill wells in areas of depletion.*

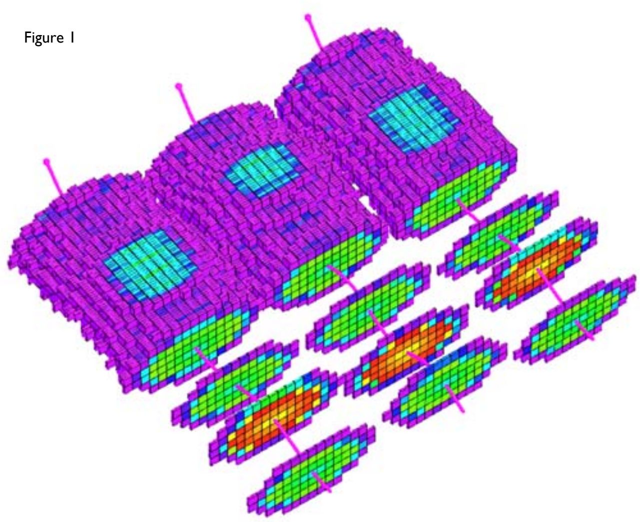
Our proven technology can address all of these issues while also providing a significantly enhanced understanding of the reservoir's and wells' performance.

Reservoir simulation, when properly employed, is the best tool available for addressing these issues. NITEC has developed unique technologies to address the evaluation of hydraulically fractured horizontal wells. These technologies utilize assisted history matching (NITEC's MatchingPro®), and a dual porosity reservoir simulator (Coats Engineering's SENSOR®) with special geomechanical modifications.

It is no longer adequate to simulate and forecast single well simulations to estimate a well's EUR. The vertical and lateral complexities of the unconventional resource, the timing of neighboring well fracture treatments and nearby well production all impact the performance of individual wells and the pad. These phenomena can only be properly captured in multi-well simulation models that account for the fracture treatment timing and well pressure and production rate responses.

The shape and character of the stimulated rock volume (SRV) are critical factors in well production performance and the ultimate depletion of the tight matrix rock. The NITEC approach utilizes geomechanical properties and petrophysical data in a finely layered simulation model, coupled with the in-situ stresses to generate tensile and shear fractures along the wellbore. These fractures and their associated properties are created in response to changes in net stress in the simulation grids caused by the fracture treatment. Stage injection rates and flow into perforation clusters are rigorously (minute-by-minute) modeled in the simulator. Fracture transmissibility and surface area that are created in this manner influences fluid transfer among the matrix, the fractures and the wellbore during the injection and production periods. Calibration of the simulation model for the fracture treatment and the flow-back and production periods results in better quantification of the hysteretic behavior of the hydraulically induced fractures and the associated fracture-matrix interaction.

Figure 1



A sample of a three well pad in Figure 1 shows the fracture (SRV) development with each fracture stage and the subsequent impact on the SRV of the next well completed in the pad.

Provider of ***LYNX®, MatchingPro®, PlanningPro®, and ForecastingPro®,*** Software

Multiple Well Model Calibration

Calibration of the simulation model is extremely important for the reliability of the predicted model performance and the understanding of the formations' fracture treatment and depletion characteristics. Accordingly, <u>calibration with multiple wells results in a more definitive model than using a single well only.</u> Figure 2 shows four actual wells drilled in the "XYZ" formation.

Wells #1, #2 and #3 were drilled, hydraulically fractured and placed on production at same time. The production profiles were very similar. The production plot for Well #1 is shown in Figure 4.

Well #4 was drilled, hydraulically fractured and placed on production approximately 2 years, 9 months after the first three wells. The fracture treatment volume of Well #4 was significantly larger than the volumes used in the first three wells. Figure 5 shows the water saturation in the fractures after the Well #4 fracture treatment. Note that in Figure 4, water production shows a significant increase at the end of the first quarter of 2012. Similar water production performances were seen in Wells #2 and #3.

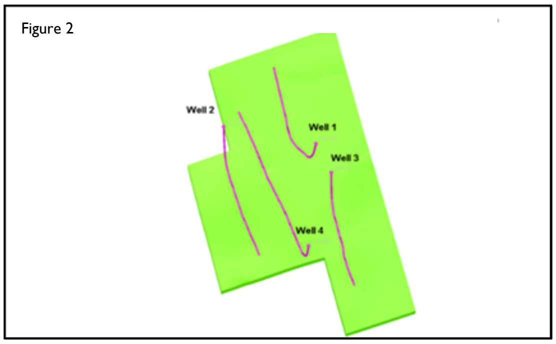


Figure 2

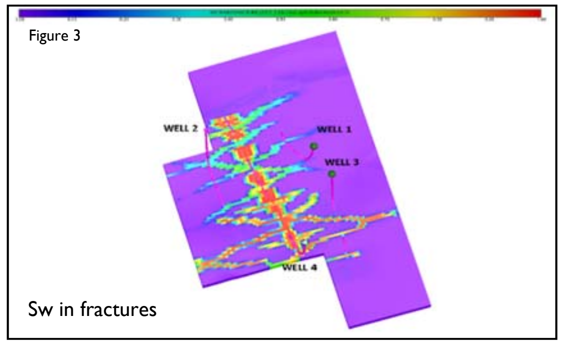


Figure 3

Sw in fractures

A small increase in the oil rate was also observed. This change in the production profile of Wells #1, #2 and #3 is clearly a result of the fracture treatment and initiation of production in Well #4 (Figure 10).

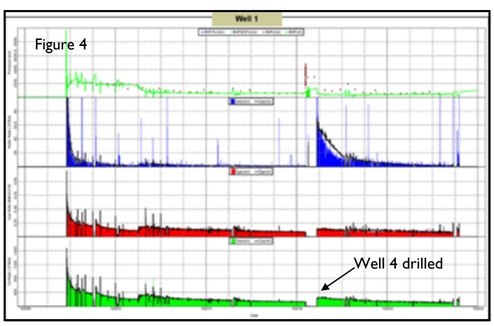


Figure 4

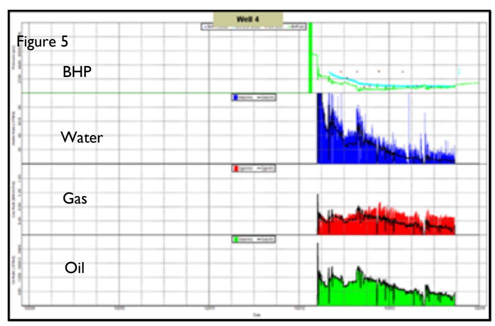


Figure 5

It is also important to note that the multi-well model automatically accounted for the impact of pressure depletion in the Well #4 area due to the earlier production of Wells #1, #2 and #3 and the associated impact on the fracture treatment and resulting SRV. While the performance of Well #4 was much better than the other wells (due to the larger fracture volume used), its impact on the earlier wells could only be determined by multi-well modeling.

This entire performance history, including the fracture treatments for each well, was history matched in the simulation model. (Solid colors are historical production, black lines are simulated production. A common set of HM parameters was used for all of the wells; no local reservoir or geomechanical parameter modifications were used. The ability to history match these different fracture treatments, production performances and inter-well communication bodes well for the predictive capability of this model.

With a well-calibrated unit area model, prediction cases can then investigate long term inter-well communication, impact of alternative operational scenarios and further infill drilling options (lateral and vertical) on incremental well and unit performance.

Sensitivity/Optimization Studies

One of the strengths of the NITEC modeling approach is the ability to conduct sensitivity studies on the impact of operational parameter changes (well length, orientation, number of fracture stages, volumes in each stage, etc.) on the predicted performance as an aid in optimizing and planning alternative development scenarios. This type of analysis cannot be reliably performed with conventional modeling approaches.

Increased Fracture Treatment Volume-Single Well: The impact of higher fracture treatment volumes (gals/ft) per stage was investigated. A case with twice the fluid volume (twice the injection rate) during each of the fracture stages and a case with four times the volume were simulated using the "base" fracture treatment volume calibrated model.

The higher volumes during each frac stage result in a larger and more intensely fractured SRV in each prediction which results in higher production rates early in the post-frac life of the well. This is quantified in the TEX parameter which represents the intensity of the fractures determined by the fracture-matrix surface area created by the fracture treatment. Figure 6 is the SRV for the 2 times base volume case. Figure 7 is the base case.

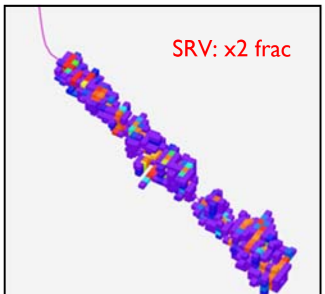


Figure 6

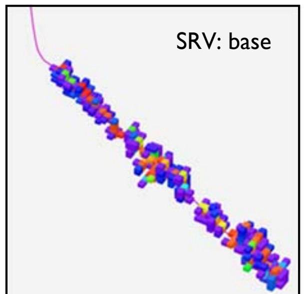


Figure 7

The production rate plot (Figure 8) for the first five years for each of the higher fracture treatment volume cases shows the rates are significantly higher in the first 2-3 years. Economic analysis will determine whether the cost of the larger fracture treatment is warranted by the increased rate and higher ultimate recovery (Figure 9). EUR can easily be estimated by extending the simulation predictions to a well economic limit.

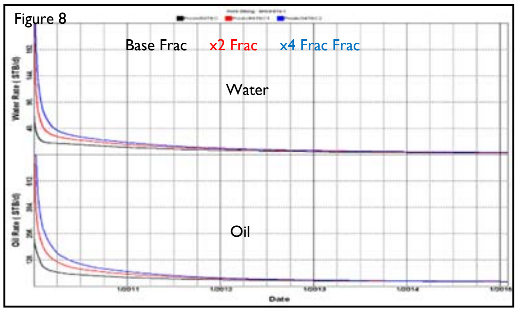
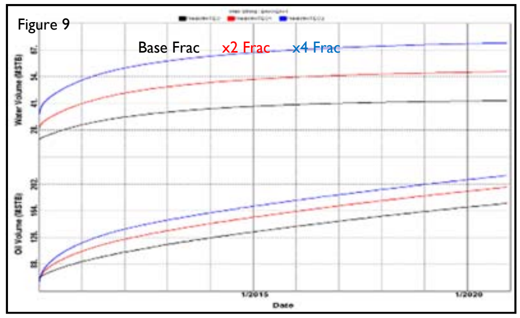
Figure 8


Figure 9


Optimize Fracture Treatment Volume and Well Spacing: A single well analysis likely will not tell the whole story. A mutli-well analysis is needed. Well spacing will have an impact on an individual well's EUR, as well as the drilling Unit's EUR. The fracture treatment design and sequence of the individual well treatments will in turn impact the EURs. A study of Unit EUR as a function of well spacing and fracture treatment volume was carried out in a thick unconventional formation. Figure 10 shows Unit EUR versus fracture treatment volume for four different spacings within the Unit (normalized results are shown). The Unit EUR increases as the fracture treatment volume increases. It is apparent from Figure 11 that individual well EUR also increases as fracture treatment volume increases, but the impact of well spacing is less evident. This case suggests that equivalent Unit EURs can be achieved with either increased fracture treatment volumes and/or closer well spacing.

Economic analysis is required to assess the best combination. NPV analysis of a series of well spacing and fracture treatment volumes can provide the plot in Figure 12 which indicates a definite "sweet spot" for the studied reservoir. This highlights the need to model multiple wells and their interaction in the reservoir.

Figure 10

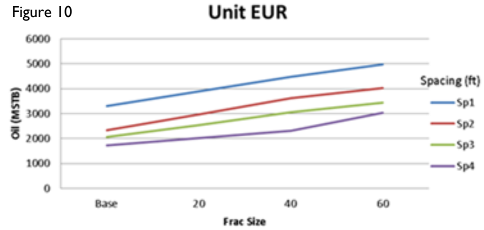
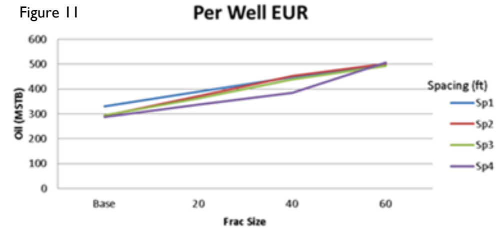


Figure 11



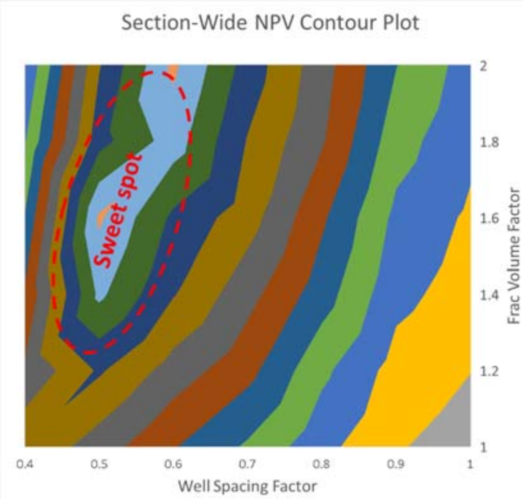


Figure 12

Summary

- **A poorly calibrated SRV in the predictive simulation model can significantly impact production forecasts.**
- **NITEC modeling approach precludes predefining SRV parameters in the simulation model which prevents bias in the prediction results.**
- **Incorporation of fracture treatment, flow-back and production in the multi-phase model calibration process allows the simulation model to be easily used to investigate production sensitivities to alternative fracture treatment parameters, well configurations, orientation and spacing.**
- **Knowledge gained in the calibration process can be applied to similar areas of the resource and future wells.**
- **Calibration of multiple wells can significantly improve reliability of the model for predictive purposes.**

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