A Comparative Study of Induced Fracture Interpretation and Modeling

How much detail is necessary?

Stuart A. Jackson and Dr. Tom Lasseter, S2S Systems, LLC*

Summary:

The interpretation of hydraulically induced fractures has been going on since we started hydraulic fracturing of oil & gas wells more than 60 years ago. Most recently hydraulic fracturing has been employed in horizontal wells in tight oil and gas fields where native permeability is not sufficient to make the wells economic. Within these wells we know that many if not most of the induced fractures are asymmetrical to the borehole. Employing seismic monitoring techniques we have the ability to observe the reservoir rock as it fractures and attempt to map and interpret the induced fractures. This technology has generated as many questions as it has answered. On the one hand it has confirmed the complexity of the induced fractures, but in doing so it has brought into question the accuracy of the observed fracture events and the fracture geometry represented by the events. The purpose of this study is to fully analyze the impact on reservoir drainage patterns associated with the most common interpretation methods for hydraulically fractured reservoirs and attempt to understand the benefits and problems associated with each method.

Introduction

Seismic monitoring of hydraulic fractures has the potential to dramatically increase recovery rates and reduce field development costs in unconventional fields. Accurate interpretation of induced fractures, correlation of them with known reservoir properties and the accurate simulation of the flow related to them will result in the need for fewer and more productive wells. Fewer wells will be needed due to a more accurate understanding of the drainage patterns associated with each well and therefore less drainage overlap. Rather than saturation drilling, new wells can be targeted specifically at bypassed hydrocarbons. As we gain a better understanding of fracture behavior we can tailor our treatments and adjust our well paths to maximize the production potential of each well. There are a number of companies working in both these areas and proving the benefits of mapping and interpreting induced fractures. However, questions remain as to how much detail is required in the fracture interpretation to maximize the benefits of seismically monitored hydraulic fracture treatments. Can we simply treat the entire volume where events have occurred (the stimulated volume) as a single porosity system or is it necessary to interpret the induced fractures and model the changing reservoir properties relative to those interpreted fractures?

Dual Porosity-Permeability Reservoirs

Most hydraulically fractured reservoirs are naturally fractured therefore the understanding of flow through a naturally fractured reservoir is crucial to constructing a realistic model of a hydraulically fractured reservoir. A dual porosity – permeability reservoir consists of two very unique flow systems; the flow out of blocks of un-fractured rock and the flow through the natural fracture system. The following diagram shows such a system.

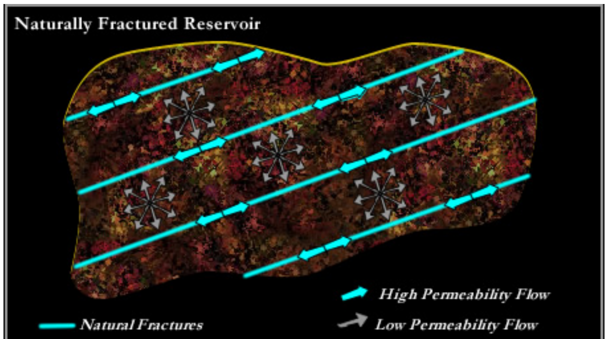

Figure #1: Expected Flow Patterns in a Dual Porosity and Dual Permeability Naturally Fractured Reservoir

The flow out of the blocks of rock into the fracture network is dictated by the effective permeability of the un-fractured rock and is generally in the order of a few microdarcies. As the gas or oil reaches the natural fracture network the effective permeability increases to that of the fracture network. Generally natural fracture networks have only a few common azimuths which are caused by common field stresses since deposition. Natural fractures are often parallel and poorly connected, making horizontal drilling and hydraulically stimulation the only way to make these reservoirs economic. Therefore the purpose of a fracture treatment is to induce fractures that will intersect the natural fracture system and create a network of "pipelines" that connect back to the borehole.

Fracture Interpretation Methods

There are currently a number of induced fracture interpretation methods that are being used to model the behavior of the reservoir after a fracture treatment. The most common is to assume the induced fractures are symmetrical around the borehole and intersect the natural fracture system (Method A) as shown in the following image.

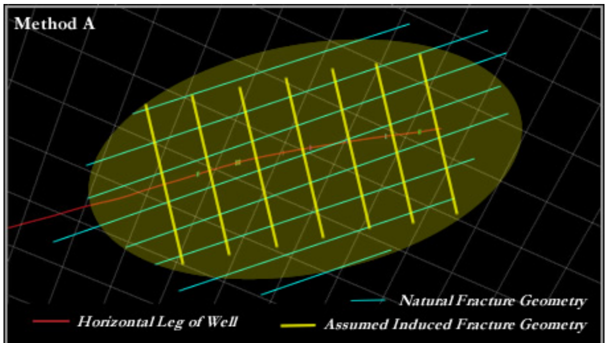

Figure #2: Expected Drainage Pattern from un-Monitored Well

This method is the most common because the majority of fracture treatments are not seismically monitored and so symmetrical fracturing is the only logical assumption.

When the fracture treatment has been seismically monitored, from nearby boreholes and/or from the surface, seismic events are recorded and provided to the client for interpretation. A convex hull can be wrapped around the events, taking into account event uncertainty and other criteria to produce a reservoir volume, or stimulated volume (Method B) similar to the one shown in Figure #3 below.

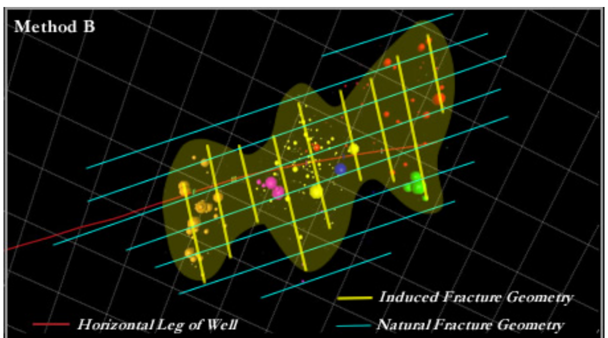

Figure #3: Expected Drainage Pattern from Idealized Fracture Pattern within the Stimulated Volume

This method would simulate the drainage from the reservoir block bounded by induced and natural fractures as well as the flow through the fracture system to better simulate the expected drainage within the stimulated volume. The properties within this volume can be adjusted to match early production history. While this type of modeling and simulation is not difficult, careful examination of its benefits relative to un-monitored treatments and to the more complex interpretation and modeling approach described below is required.

The final fracture interpretation method that is being examined assumes that it is more likely that large discrete fractures have been induced in the reservoir (Method C) rather than the creation of an intricate network of induced and natural fractures. This fracture interpretation method provides for the effective reservoir permeability to be increased in proximity to these discrete fractures as the following image demonstrates.

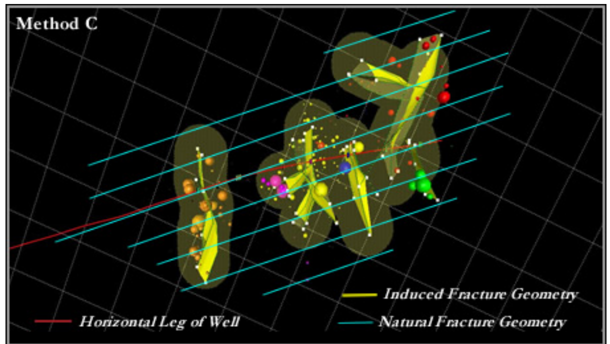

Figure #4: Expected Drainage from a Realistic Fracture Pattern within the Stimulated Volume

This method accounts for the likelihood of a greater frequency of natural fractures being activated near the induced fractures and less with increased distance from the induced fracture until the native reservoir properties are reached. Assuming this approach yields a more accurate representation of the reservoir, it is more difficult and time-consuming to construct and does require fully integrated models and an expert understanding of the geology, therefore we need to examine what benefits it provides over previously described interpretations and whether it's worth the effort.

Reservoir Drainage

Whether the stimulated volume is symmetrical or guided by observed seismic events, Methods A & B require a two step simulation approach to reach the maximum benefits described in the introduction, namely a drainage map of the entire reservoir. The first simulation step would involve the drainage of the stimulated volume and the second step would involve the flow from the naturally fractured reservoir into the stimulated volume and ultimately to the wellbore. Both methods assume that an intricate network of induced and natural fractures has been created so the reservoir properties and the induced fracture spacing can be manipulated to match early production and simulate future drainage. Possible problems with this approach are the sometimes unrealistic properties and fracture spacing required to match production and the assumption of constant rate drainage from the entire stimulated volume.

The more realistic model described in Method C recognizes that regular spacing of induced fractures may be desired but is very unlikely and that natural fractures are more likely to be activated the closer they are to induced fractures. Therefore, by simply increasing the effective permeability from that of the naturally fractured reservoir to a value required to match early production, a very accurate and realistic model can be constructed and ultimately simulated.

Simulators

Most simulators currently used within the industry are not capable of easily handling the complex fracture geometries within a naturally fractured reservoir. If they are, it is very difficult and time-consuming to integrate induced fracture geometries into these reservoir models for simulation.

Conclusions

While the benefits from this detailed and integrated approach

Future Work

All the fracture interpretation and modeling methods described above, produce a dual porosity – dual permeability reservoir model. There is considerable discussion in the industry as to whether this level of detail is required to accurately simulate the drainage from a fractured reservoir. Future work will be conducted to simulate each of the three methods with both dual and single porosity-permeability models and quantitatively analyze the benefits of each.

Once we are capable of producing monitored events in near real-time and quickly interpreting the induced fractures and simulating the expected drainage based on past well performance, we can more precisely place adjacent wells to optimize drainage. Optimized well placement will result in fewer wells required to drain larger percentages of the field. Furthermore, we will have an accurate map of the produced areas and remaining reserves which I understand is helpful to the financial types.