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Technology Maps Fracture Complexity

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HOUSTON–As infill drilling increases in unconventional resource plays, some operators believe updating their completion strategies is necessary to increase estimated ultimate recovery rates at reduced cost per barrel of oil equivalent. The thinking goes that the best practices they have relied on in the past may not necessarily be the ticket to the future as well spacing decreases to maximize hydrocarbon production.

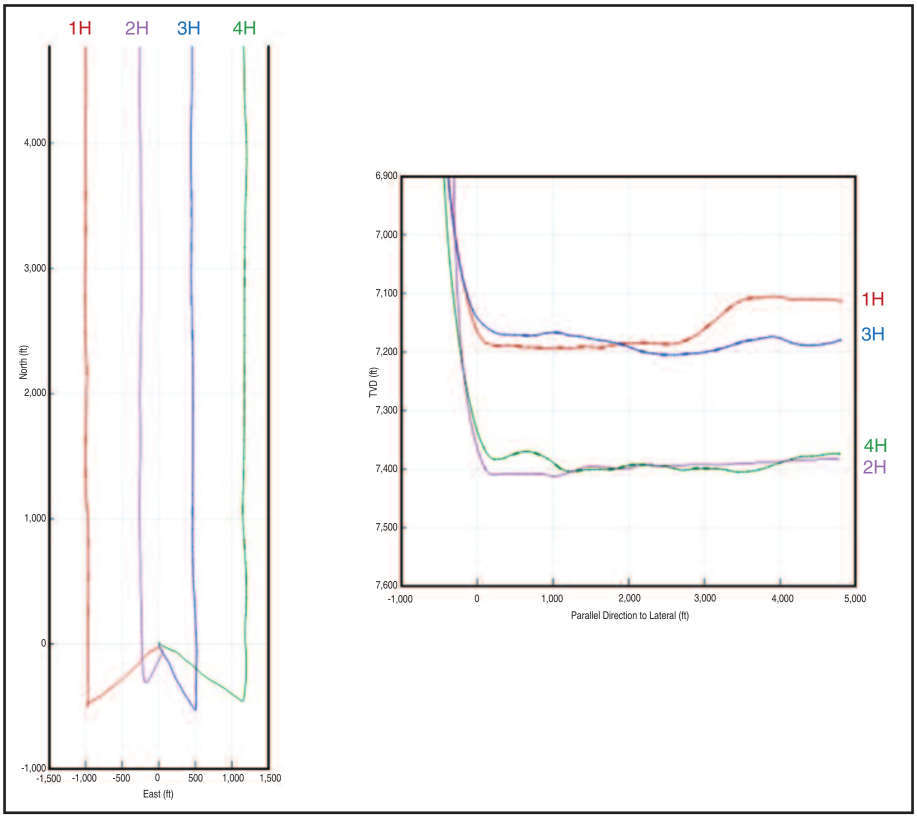
Alta Mesa Resources was one of the STACK operators thinking about this well-proximity paradigm, and decided the time was right to try a new systematic and rigorous approach. So the company set out, originally, to evaluate its completion strategy using two fracture diagnostic techniques: microseismic mapping and a new pressure-based fracture map technology. But something happened along the way of comparing the diagnostic techniques. The operator had to shut down the pumps, which led to significantly greater completion design insight that was documented only by pressure-based fracture maps.

Of course, shutting down the pumps for fluid or equipment reasons is nothing new, but in this case, the downtime acted coincidentally as a fracture growth inhibitor that increased fracture propagation relatively near the wellbore. A short pumping pause created near-wellbore complexity that was not seen on stages without the pumping pause. Those stages in which there had not been a pumping interruption showed more linear fracture growth with a dominant fracture taking most of the fluid.

These scenarios were identified and documented by simple, accurate pressure-based fracture maps, and the operator then validated the findings with microseismic. Given the validated pressure-based fracture maps can be applied with less effort and expense than microseismic, Alta Mesa Resources believes this new technology is an excellent tool for optimizing its completions.

FIGURE 1

Four-Well Pad Layout



Four-Well Pad

Figure 1 shows an Alta Mesa Resources-operated four-well pad layout, with wells vertically staggered in two horizons in the eastern portion of the STACK play in the Anadarko Basin. The pad includes one parent and three infill child wells. The Woodford Shale is one of the best known and most drilled formations in this part of the STACK play, but the area also includes promising formations such as the Chester, Hunton, Meramec, Osage and Oswego stacked

FIGURE 2A

Linear Fracture Growth

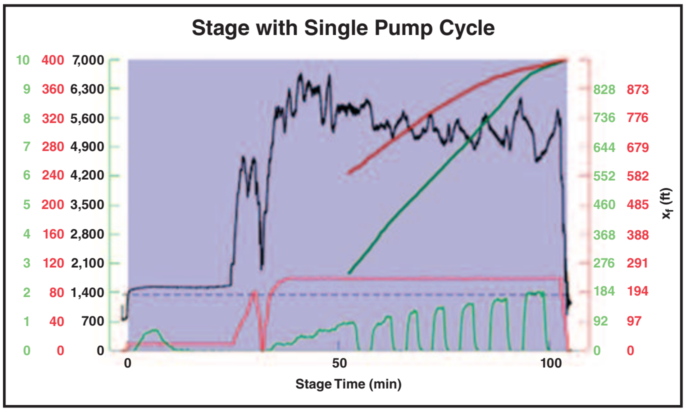
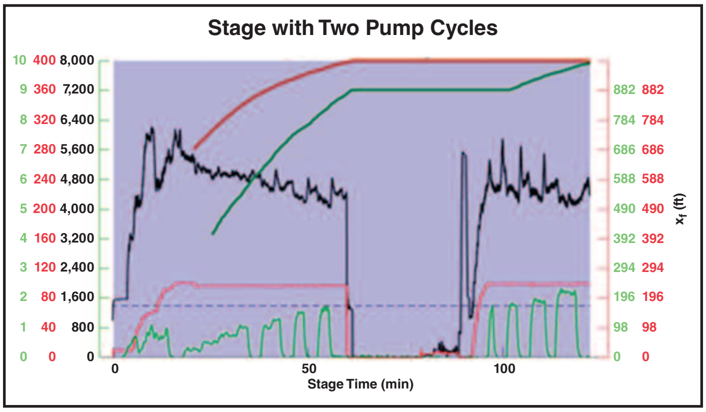


FIGURE 2B

Complex Fracture Growth



on top of one another.

The main goals of the study were:

- Demonstrating the use of pressure-based fracture maps as an effective diagnostic tool;
- Examining and characterizing the interwell communication created by current practices;
- Investigating differences in fracture growth caused by pattern fracturing; and
- Identifying completion designs to generate greater complexity.

Fracture stimulation in the Woodford reservoir primarily aims to connect natural fractures to the wellbore. Significant interwell communication and production interference can result when applying completion practices designed for a lone well. It is desirable to identify a completion design that will reliably limit bi-wing fracture growth, increase fracture complexity and enable increasing the stage length. This will not only provide better hydrocarbon recovery, but also will help optimize drilling and completion costs.

The original project scope was to evaluate Alta Mesa Resources' current completion strategy using the various fracture diagnostic techniques. As noted, however, new key findings were discovered from unplanned events. Like most hydraulic fracturing operations, equipment and mechanical failures are common, which could include anything from the fluid side, such as blending equipment and low-pressure line leaks, to the iron side, such as pump failures and high-pressure leaks.

It is not optimal to shut down during a hydraulic fracturing stage because of an equipment failure; however, at times shut down is unavoidable. This scenario occurred on a select group of stages throughout the completion, leading to a discovery of the effects these shutdown events were having on the near-wellbore complexity.

It was observed that shutdown effects inadvertently inhibited fracture growth, which allowed the increase in fracture conductivity in the near-wellbore area. This inhibition of fracture growth was not observed for any of the stages where these shutdown events did not occur. This led to the investigation of varying pump rates to capitalize on fracture complexity. Pressure-based fracture maps identified this phenomenon of increased near-wellbore complexity, which was not easily distinguishable using conventional microseismic interpretations.

New Diagnostic Tool

Legacy diagnostic technologies can be intrusive, expensive and time consuming. Alta Mesa Resources decided to apply a new oil field diagnostic tool: the integrated modeling approach for geometric evaluation of fractures that would overcome many of the challenges of legacy technology and provide a cost-effective and reliable solution to perform fracture diagnostics.

The pressure-based fracture map technology is based on the poroelastic pressure response that occurs during normal hydraulic fracturing of treatment wells. The pressure response is recorded by a surface pressure gauge from one or more monitor stages in wells adjacent to the treatment well. The monitor and the treatment wells can be interchangeable. The continuous pressure data stream from the monitor well does not interfere with normal hydraulic fracturing in the treatment well and does not require downhole tools or cause downtime.

After acquiring the pressure data in the monitor stages, poroelastic pressure responses must be differentiated from pressure responses caused by direct fluid communication or diffusive fluid transport. Once identified, poroelastic signals can be used to calculate hydraulic fracture geometry by matching the observed responses in the monitor stages to a digital twin. The output, which is the fracture map, is the fracture dimensions of half-length, height, asymmetry and azimuth, and how fast those dimensions grew.

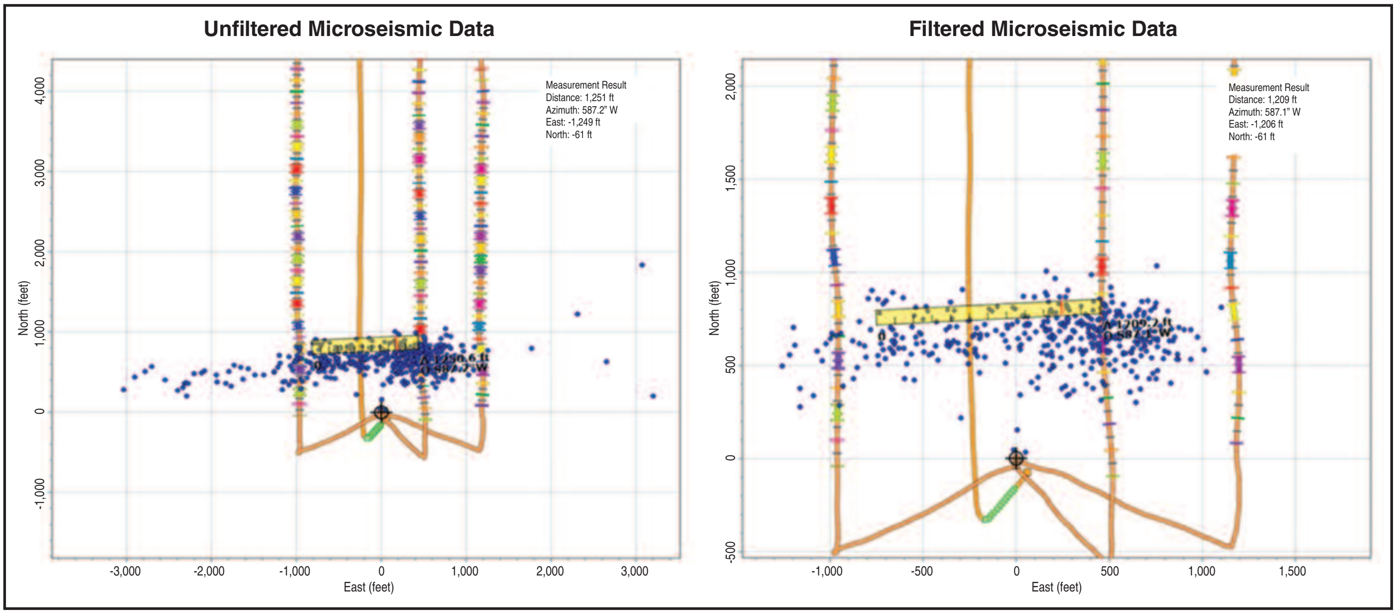
The technology maps the largest hydraulic fracture per stage. Impeded growth of that largest fracture during completions can be interpreted as improved fluid distribution in that stage. The timing of when the largest fracture growth is impeded allows the differentiation of whether the generated fractures are mostly bi-wing or whether near-wellbore complexity has been achieved. As in this case of the four STACK wells, this complexity was validated with microseismic data.

Creating Complexity

A key goal of the Alta Mesa Resources project was to evaluate the ability of various treatment designs to prevent bi-wing fracture growth and generate fracture complexity. One of the methods explored in the past looked at reducing the stage length to promote complex near-wellbore fracture growth. Completions with shorter stage lengths become expensive, resulting in diminishing economic returns. Completing these wells with longer stages is desirable, but this design requires generating multiple fractures from a given stage and creating near-wellbore com-

FIGURE 3

Microseismic and Pressure-Based Fracture Map Results



plexity.

Pressure-based fracture maps provide a unique ability to distinguish linear bi-wing fracture growth versus multiple fractures with near-wellbore complexity. Pressure-based fracture maps quantify the growth rate of the largest fracture in a given stage, which provide insight into the development of near-wellbore complexity.

The fracture dimension of the largest fracture in the stage, such as fracture half-length or fracture height, continues to increase over most (if not all) of the volume of fluid pumped into the treatment stage. This results from a single fracture taking most of the injected fluid, causing continuous growth of this dominant fracture. On the other hand, when complexity develops, fluid flow into the largest fracture is reduced, stopping its growth.

As noted, most of the stages were completed using a single pump cycle: 98 percent of the stages treated without interrupting the pump cycle showed fracture dimension of the largest fracture growing over the entire pumping schedule. This indicated that many of these stages had linear bi-wing fracture growth.

Varying the pump rates resulted in generating near-wellbore complexity. Several stages on this four-well pad were treated with two cycles with a prolonged gap between the cycles. Figure 2A shows a stage treated with a single pump cycle, while Figure 2B shows another stage treated in two pump cycles. The red and the green curves are the computed fracture growth curves, with the red curve plotting the fracture growth on the west side of the fracture and the green curve plotting growth on the east side of the fracture.

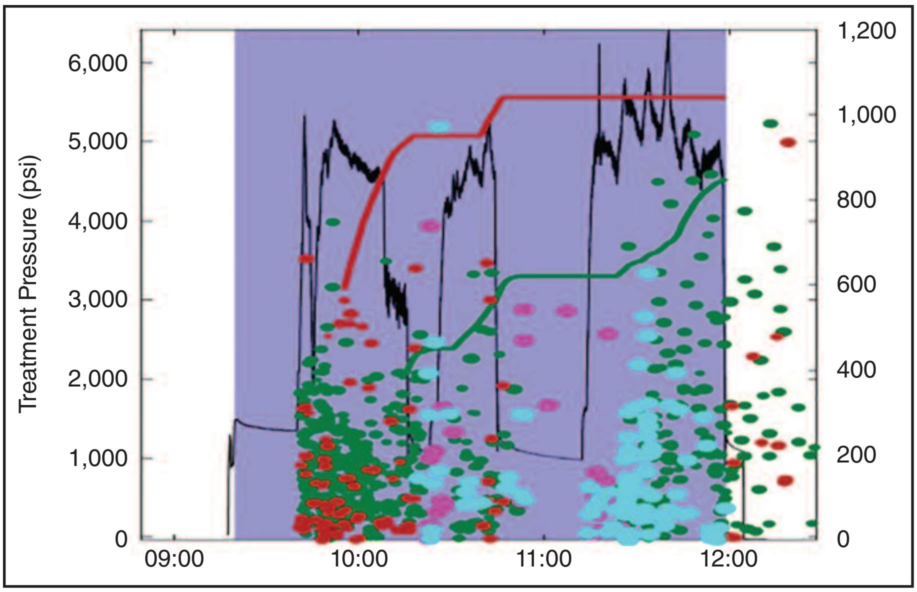
It is apparent from the pressure-based fracture map results that stopping the pumps in the middle of the stage resulted in stopping the growth of the largest/dominant fracture. Resuming pumping after a short pause created a diversion effect, resulting in very limited growth of the largest fracture. This also indicated that the pause in pumping was creating near-wellbore complexity.

Case Study Results

Both pressure-based fracture maps and microseismic data were collected on the three child wells completed on the

FIGURE 4

Fracture Complexity from Pressure-Based Fracture Maps



pad. Figure 3 shows a comparison of pressure-based fracture map and microseismic results. The unfiltered microseismic data measured half-length that far exceeded the half-length from pressure-based fracture maps. The microseismic data were filtered to only include events occurring during the fracture stage and further filtered to remove microseisms in the top layers that were believed to be unconnected with the induced fracture network.

With this filtering, there is good agreement between the pressure-based fracture map half-length and the microseismic half-length (Figure 3), although the microseismic length is generally longer. Asymmetry is reflected consistently between the microseismic and pressure-based fracture maps. Pressure-based fracture maps show the hydraulic fracture height to be constrained within the target horizons while the microseismic data show significant activity in layers both above and below the target horizons.

Figure 4 compares the microseismic data with the fracture growth curves computed from pressure-based fracture maps. Again, the red and green curves are the fracture growth rates on the west and east sides, respectively, of the fracture. The red (west) and green (east) dots represent the microseismic events on both sides of the fracture, plotted as the distance from the wellbore shown on the right axis.

The microseismic events were separated to correspond with the time the largest fracture was growing and when the largest fracture stopped growing. The pink and the light-green dots are from the time when the largest fracture stopped growing. One can clearly see that most of the microseismic activity is near the wellbore, consistent with the analysis from pressure-based fracture maps that the largest

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Sean Rosenfeld is a completion engineer with Houston-Based Alta Mesa Resources. He previously worked as a hydraulic fracturing engineer at Baker Hughes, a GE company, and Producers Service Corp. In these roles, Rosenfeld designed stimulation treatments and executed field trials. One project involved careful fracture placement in a mature waterflooded field with injectors on the assumed fracture plane. It has since evolved into a horizontal drilling pilot project. He holds a B.S. in chemical engineering from the University of California, Los Angeles.

SUDHENDU "KASH" KASHIKAR

Sudhendu "Kash" Kashikar is chief executive officer of Reveal Energy Services, which has developed pressure-based fracture maps that have now been applied in more than 6,500 frac stages. He has 25 years of experience in bringing new technology to market and holds several patents, including on pressure-based mapping. Before joining Reveal Energy Services, Kashikar worked in technology, operations and business development roles at Microseismic Inc., Silixa and Schlumberger. He has a B.S. in petroleum engineering from the University of Pune and an M.S. in petroleum engineering from the University of Oklahoma.

JUSTIN MAYORGA

Justin Mayorga is a completion engineer with Reveal Energy Services. Before joining the company, he worked for Halliburton as a hydraulic fracturing engineer on various projects in North America unconventional plays. On one project, Mayorga analyzed refrac treatments in the Haynesville Shale and presented engineering recommendations that optimized fracturing design and performance. He holds a B.S. in petroleum engineering from The University of Texas at Austin.

fracture stopped growing when the pump cycle was paused.

Results from the STACK field trial clearly demonstrated that the pressure-based fracture maps provide an effective fracture diagnostic tool. These measurements were much simpler to acquire in the field, eliminating additional field personnel for running fracture diagnostics.

The data offer Alta Mesa Resources a practical approach to ensure continuous learning that will improve the company's completion designs to achieve cost reductions and maximize recovery.

Additionally, the results have led to trials of new completion practices to optimize infill well placement and development. Because of the cost-effectiveness and repeatability of the pressure-based fracture maps, further comparative "A/B testing" using new completion schedules and measuring the respective growth rates is being performed to increase confidence and to allow a direct relation with production results. As effective tools and changes to the completion design are identified, better options for stage length, well placement and frac volume are becoming available.

Future plans include instrumenting study wells to allow better examination of each well's deliverability so that the value added by completion design changes can be quantified. The results of pressure-based fracture maps have led to an increased understanding of the reservoir in the STACK/SCOOP area and have allowed Alta Mesa Resources to be one step closer to developing completion designs tailored to increasing fracture complexity, providing additional reservoir drainage. ❐