OPERATING UNDER PRESSURE

Sudhendu Kashikar, Reveal Energy Services, USA, shows how pressure-based fracture maps allow for informed decisions and increased efficiency.

Early in 2015, a Statoil R&D team decided to confront a decades-old challenge. Even though the industry had been fraccing wells for nearly seven decades, understanding and mapping of fracture growth remained elusive, often preventing informed decisions about full-field development. The reason was simple: the existing fracture map technology could only be applied to a limited number of wells because the cost was prohibitive.

The team went to work knowing a digital transformation could address the cost issue that would, in turn, address the full-field necessity for a comprehensive insight into fracture growth and the mapping of the fracture network. If successful, the team would be able to offer the industry greater awareness into why all of this is vital in the first place: the issue of geologic variability that can cause wells even very close together to produce vastly different amounts of oil.

The R&D work proceeded swiftly. By the second half of 2015, the team began internal validation studies of what was called an integrated modelling approach for geometric evaluation of fractures or IMAGE Frac™ technology. The technology is based on a pressure gauge on a monitor well to record the poroelastic pressure response from a nearby treatment well that was hydraulically fractured. The purpose, and the foundation of the new approach, was to create a pressure-based fracture map, an industry first.

Early in 2016, the team began what turned out to be successful pilot projects. Following this external technology validation, the venture capital group, Statoil Technology Invest, created a spin-out entity, Reveal Energy Services, in late 2016, with IMAGE Frac technology as the foundation of the company. This oilfield services company startup has an exclusive license to the pressure-based fracture map technology and the essential patents.

In addition to offering a 3D fracture map of half-length, height, asymmetry, and azimuth, the pressure-based fracture map data support four other applications that allow operators to:

- Determine how far proppant has been placed within the fracture.
- Understand whether a diversion design is working.
- Know if fluid is distributed equally between multiple clusters.
- Identify the depletion boundary surrounding a parent well.

The simple, accurate, affordable pressure-based fracture map is part of the oilfield's digital transformation with data analytics that is offering greater insight into the completion parameters that affect production, ensuring informed decisions that replace hydraulic fracturing efficiency.

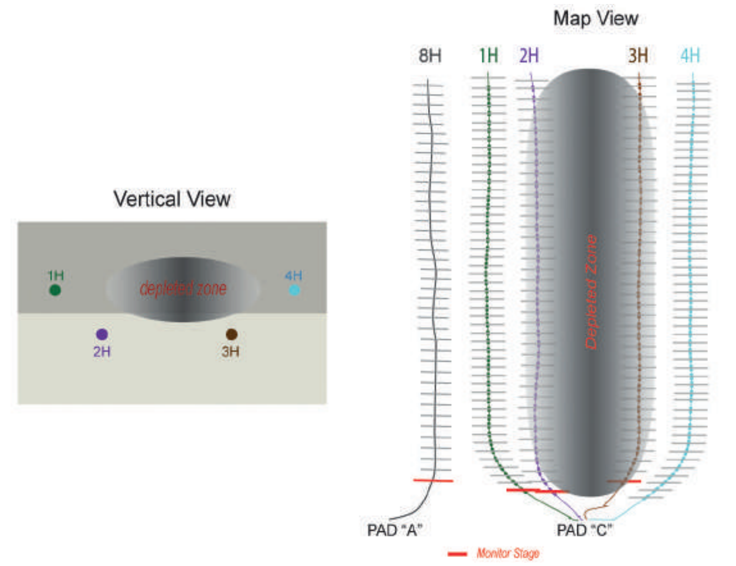

Figure 1. *Four-well pad, Bakken. This is the vertical view and map view of the four wells on pad C in the Bakken case study.*

How big is the fracture and how fast is it growing?

A simple pressure gauge, with rigorous R&D, is the source of this new fracture map, which is based on principles of poroelastic theory and fluid flow-through porous media. The fraccing of at least two wells on the pad proceeds in the following sequence:

- Create a monitor well by setting a bridge plug before fraccing a stage on that well.
- Frac the stage.
- Shut in the well and install a pressure gauge on the wellhead.
- Frac well 2, known as the treatment well, using standard operating procedures.
- Record the pressure data from the monitor well as fraccing proceeds on the treatment well.
- Transmit the real time data to Reveal Energy Services.

The monitor well can be as far away as 2500 ft, or nearly half a mile, from the treatment well. The continuous pressure-data stream from the monitor well does not interfere with normal hydraulic fracturing in the treatment well nor does it require downhole tools or cause downtime.

New fractures in the treatment well generate a stress field pressure response in the monitor well. The company uses that response to

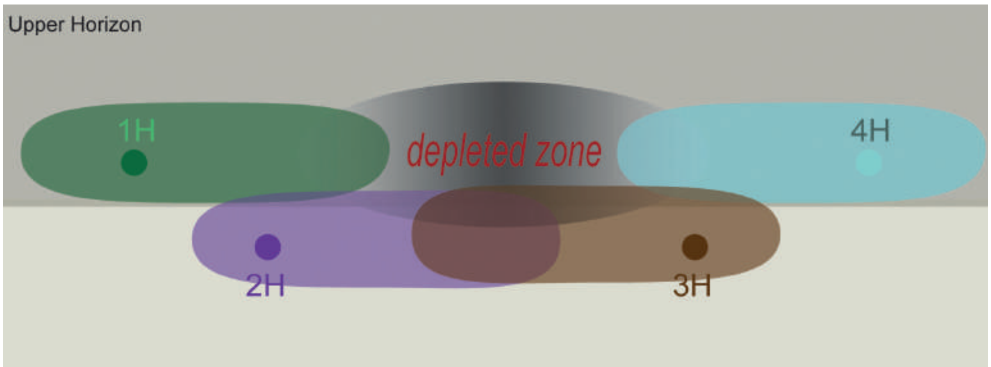

Figure 2. *Fracture geometry. This is a vertical view showing the heel stages' average fracture geometry. Significant asymmetry observed on the pad's four wells documents that the depletion zone extends into the lower horizon.*

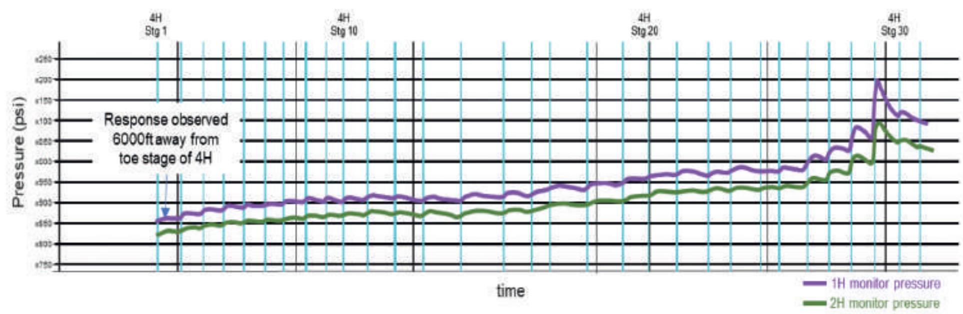

Figure 3. *Monitored well pressure data. The pressure recorded on wells 1H and 2H shows a pressure response 6000 ft from a stage being fractured on well 4H. The well 4H fractures are pressurising the depleted zone. With this information, the operator can make treatment design changes to prevent fractures extending into the depleted zone.*

compute the pressure-based fracture map, quantifying fracture geometry growth for each stage being treated. An experienced team of geoscientists and engineers overlay the observed pressure response in the monitor well with the corresponding modelled pressure response. The output, which is the fracture map, is the fracture dimensions of half-length, height, asymmetry, and azimuth and how fast those dimensions grew.

Within a short time frame and at a fraction of the cost, the pressure-based fracture map diagnostic tool is supporting well objectives with relevant data in relevant time. Older fracture mapping methods, which rely on legacy technology, are 10 - 20 times costlier and can take significantly longer to generate.

Now, operators have affordable, expedited data analytics that allow them to adjust their completion designs to match a development's varying geology. By confirming the completion is producing the planned fracture dimensions, the pressure-based fracture map allows operators to make informed decisions that support their goal of working with factory mode consistency to increase pad commercial value in each unit.

Depletion map case study

As the industry moves into full field development, the challenge is to drill and complete wells close to existing producers. Because these wells have been on production for several months to several years, there is a significant depletion zone around each well. These depletion zones pose some unique challenges to the hydraulic fracturing of nearby wells. Some of the more common challenges are:

- Increased asymmetric fractures.
- Limited stimulation of the newly created fractured in child wells.
- Reduced production from the original producer and newly fractured wells.

The company's pressure-based fracture map is a cost-effective technology that can identify, in real time, when a newly created fracture in the child well is affected by the depletion zone challenges discussed above. With this knowledge, operators can make an informed decision about their completion design, as is discussed in the following case study.

An operator, completing a multiwell pad in the Bakken, had four wells on pad C that were completed in two separate horizons on either side of a depleted parent well, as shown in Figure 1. Wells 1H and 4H are in the same horizon as the depleted parent well while wells 2H and 3H are in the lower horizon. Well 8H on pad A would be used as a monitor well while zipper fraccing wells 1H, 2H, and 3H on pad C. The operator's objectives were understanding if wells 2H and 3H would be affected by the parent well depletion; understanding the extent of the depletion zone; and evaluating strategies to protect the parent well and improving the effectiveness of fracturing the child wells.

Depletion-induced fracture asymmetry

As part of the operator's objectives, the first step was to compute the fracture geometry and fracture asymmetry for wells in the upper and lower horizon. Pressure data recorded from the 8H monitor stage enabled Reveal Energy Services to compute the fracture geometry growth on pad C. Figure 2 shows the results of the fracture geometry for the heel stages of the four wells. The fracture growth rates were computed independently in near real time. Significant asymmetry was observed in the fracture growth towards the depleted well. The asymmetry was not limited to the wells in the same horizon as the depleted parent well, but was also observed in the wells in the lower horizon. Wells 1H and 4H, in the same horizon as the depleted parent well, demonstrated slightly higher asymmetry while wells 2H and 3H, in the lower horizon, demonstrated less asymmetry.

How does this information help the operator? Understanding the timing of fracture growth and degree of asymmetry lets the operator know about the changes necessary in the treatment design to prevent fractures extending into the depleted zone while also improving the effectiveness of the fractures in the unstimulated region. Asymmetric fracture growth is easily and quickly identified before fracturing the next stage. Adjustments in the diversion scheme, pumping rate, and proppant schedule are made while fracturing the subsequent stage.

Depletion-induced pressure communication

The operator's secondary objective was to understand the extent of the depleted zone and its interaction with the newly created fractures. Figure 3 shows the pressure response recorded in the monitor stages of wells 1H and 2H while fracturing well 4H. Pressure can be seen building up in the monitor stages while fracturing the toe stages of the 4H, which is more than 6000 ft away from the monitor stages. Based on the poroelastic response simulation, pressure was not expected to be seen at this distance away from the stage being fractured, which is typically 2500 ft.

The asymmetric growth of the newly created fractures was pressuring the entire depleted zone, resulting in the increased pressure seen at the monitor stage. Comparing the pumping schedule with the timing of pressure response at the monitor stage suggested that most of the fracture growth was occurring toward the depleted zone and not effectively creating new fractures in the unstimulated region.

Near real time knowledge of depletion-induced pressure communication and depletion-induced fracture asymmetry enabled the operator to take timely corrective steps to modify the completion design and achieve more effective fractures. This enhanced fracture geometry can be achieved through a combination of a protection refrac on the parent well and a properly designed diversion schedule on the treatment well. This strategy offers sufficient protection against wasting fracturing fluid into the depleted zone, in addition to achieving improved fracture geometry for the newly created fractures in the child wells.

Conclusion

A pressure-based fracture map with fracture geometry of half-length, height, asymmetry, and azimuth is a simple, accurate, affordable diagnostic tool to understand the interaction between a depleted parent well and the neighbouring child wells. With this information about fracture geometry, operators can also conduct properly designed tests to rapidly determine how far proppant has been placed within the fracture, understand whether a diversion design is working, and know if fluid is distributed equally between multiple clusters. All of this data is vital in order for an operator to make informed decisions that increase hydraulic fracturing efficiency.