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Fracture Monitoring Technology Allows Operators to Optimize Treatments in the Field in Real Time

During a fracturing treatment, a big issue for both the operator of the well and the stimulation design engineer is that the fracture is being created according to fracture modeling performed prior to the treatment. Among the concerns are: Is this fracture modeled correctly? Do we know where it's going?

The answers to these questions can be provided by information gained from microearthquakes. Most microearthquakes occur naturally but, some are man-made. Non-naturally occurring microearthquakes, or microseismic events, arise from changes in stress and pore pressure associated with some man-made event such as the hydraulic fracturing of an oil- or gas-bearing formation. Microseisms are seismic waves induced by the microearthquakes.

Passive microseismic monitoring is a technology that exploits these microseisms in order to evaluate hydraulic fracture propagation. The importance of this technology is that it can provide real-time assessments of the fracturing process for the operator and stimulation engineer while the job is underway. As a result, operators can optimize their in-fill drilling program, improve their subsequent frac jobs and minimize the uncertainty in their fracturing programs.

Applications of passive microseismic monitoring include mapping the extent of fractures during hydraulic fracture treatments, fault mapping, and tracking a gas or water front for assisted recovery production. In order to improve on the application of 3D hydraulic fracturing modeling and processes, the location and growth of hydraulic fractures in real time must be known in terms of fracture azimuth, length, height, and growth history. To accomplish this goal, each microseismic event detected by the seismic acquisition system during a stimulation treatment is transferred to a second computer system to determine the location of the event in time and XYZ coordinates with respect to the treatment wellbore, and time-stamped to the real-time stimulation job data (treating pressure, rate, proppant concentration, etc.). Since the monitoring of gas or water flood fronts is a microseismic application, it requires permanent seismic sensors and the applications are referred to as 4D



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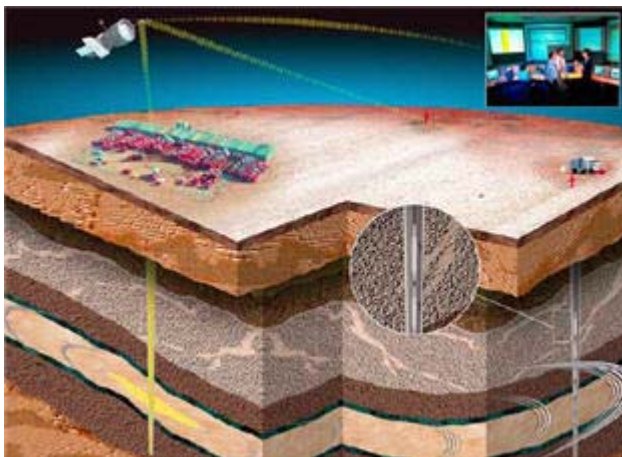
ExactFrac™ Service

Fracture monitoring using microseismic technology was conceived approximately 40 years ago as an extension of fault movement monitoring. This technology has enjoyed resurgence during the last 10 years due to technology developments in the borehole seismic sensors.

Articles published in the mid 1980s discuss hydraulic fracture monitoring using a triaxial geophone located in the *same borehole* in which the hydraulic fracture treatment was being applied. Monitoring in the same borehole, creates many obstacles; microseismic monitoring cannot be performed during pumping due to the background noise of the treating fluid flowing past the seismic sensors and the required reduction in injection rate due to the string of tools in the wellbore. Monitoring in the same wellbore as the treatments can only be performed after pumping, and the events are generally located in the *far-field*.

However, current technology generally prefers a *two-well process* for hydraulic fracture monitoring. On pad locations, a single monitor well can be utilized for multiple well stimulation operations.

To exploit the benefits of passive microseismic monitoring, Halliburton recently developed the ExactFrac service. The technology combines Halliburton's considerable background in logging technology, and borehole seismic services with the science of microearthquakes to allow the monitoring of fractures while they are being created. Thus, fracturing engineers can obtain the answers they require from this full-service approach to logging that offers both dipole sonic utilized for the pre-stimulation stress profile modeling and the velocity profile for the borehole seismic modeling.

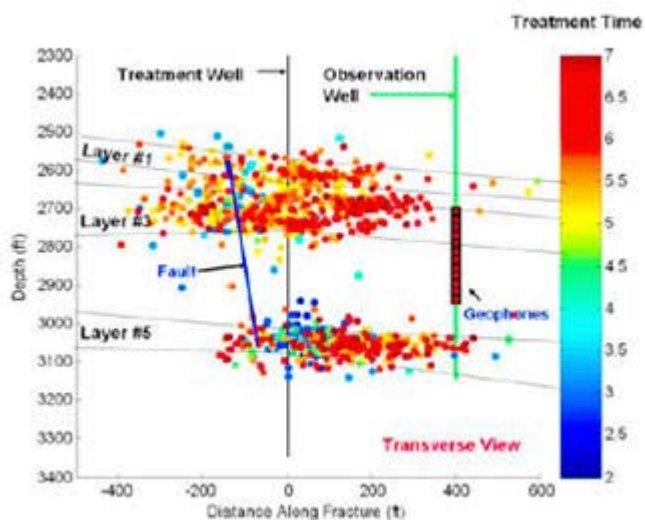


The ExactFrac™ Service places sensitive geophones in the offset well to gather seismic activity as the hydraulically induced fractures propagate into the formation. (Click image to enlarge)

The system is based on proven borehole seismic sensor technology and has been designed for use in open and cased holes using standard 7-conductor cable. An array of 3-in. OD downhole geophone sensors rated at 20,000 psi and 354°F are available to be used in hole sizes from 3-1/2 in. to 22 in. A special high-pressure version can be utilized for pressures up to 25,000 psi. Sensors with a temperature rating of 400°F will be available Q3-Q4 2007. The seismic acquisition system uses a telemetry rate of 1.5 Mbps, which allows 0.5 ms sampling rate.

Job execution

Generally, the seismic acquisition and processing software system is set up the day before the fracture treatment is to be performed in the monitor well. During emplacement of the seismic receiver array in the borehole, the individual geophones are clamped to the wall of the casing by an internal mechanical mechanism. The orientation of the individual tri-axial sensors can be on any fixed X-Y direction. Pre-job set-up requires conducting perforation or string shots in the treatment well and recording the resulting waveform in the monitor well. This process of mathematically rotating the individual geophone sensors to a standard reference direction is known as "orientation." If a perforating or string shot cannot be performed, a surface vibroseis truck can be used for the orientation process.



The ExactFrac™ Service reduces cost and optimizes well spacing and well placement. (Click image to enlarge)

Several methods, including direct downhole measurement or purposeful source activation ("shooting") are available to obtain the angular information used in the orientation process. In any

case, software implementation of the fracture monitoring processing system allows for, and can use, the orientation provided by the seismic software processing system; or optionally, the orientation can be recomputed for any number of perforations or frac stages.

During a hydraulic fracturing treatment, ExactFrac Service utilizes microseisms (microearthquakes) that have been induced by the changes in stress and pore pressure associated with hydraulic fracture propagation. This seismic event is detected by an array of tri-axial receivers situated in a monitor well at a depth comparable to the microseismic "events." The compressional (primary or P) and shear (secondary or S) waves from the events are detected and the location of the events (X-Y-Z distance and azimuthal orientation) from the treatment well are determined in real time. Because these microseisms are extremely small, sensitive and accurate receiver systems are used to obtain valid results.

Background noise and microseismic events are continually recorded by the borehole seismic array and transmitted up hole by the seismic acquisition system for processing and analysis during and after the frac treatment. Such spurious information continues for a period of time after the pumping operation has ceased until no additional events are detected. While the data is acquired, events detected by the acquisition system are processed on a second computer. This second computer allows real-time event location and optimization of the processing parameters. It should be noted that seismic acquisition event detection is generally quite simple, and based upon both P-wave and S-wave arrivals.

Also, the availability of a second computer provides the on-site "frac monitoring system" the option of re-analyzing all complete data records utilizing later in time optimized processing parameters. Alternatively, the system can analyze just selected data acquisition segments, typically of one second duration, for which an event has been detected by the acquisition system. The time stamped microseismic event locations with respect to the treatment well are transmitted to the wellsite stimulation tech command center, and to the client's office utilizing Insite anywhere.

Service benefits

When utilized to monitor stimulation treatments, this newly deployed technology enables operators to optimize their drilling programs for optimal field development and optimization of later frac stages, or jobs, by selectively treating zones which exhibited minimal out of zonal height growth, and fracture length and conductivity for economical production rates. Finally, it minimizes

the uncertainty in operators' fracturing programs.

ExactFrac service in the field

Case History No. 1

Operator Challenge:

This major operator was seeking more accurate placement of his fracturing treatments in a reservoir which consisted of many thousands of feet of interbedded sandstones and shale sequences. Lenticular sandstones, are often referred to as stratigraphic plays, and are often difficult to correlate from well-to-well. A simple geological explanation is to picture the sand bodies as stacked ellipsoids with random symmetry with respect to the wellbore.

The Solution: After consultation with Halliburton, the operator chose to perform an ExactFrac service mapping of the stimulation treatments. The Exact Frac mapping of the many stimulation stages provided a 3D picture of the reservoir, and the fracture drainage patterns.

The Result:

As a result of the ExactFrac mapping, many asymmetrical fracture wings which described the limited lateral extent of some of the sand lenses from the wellbore along the strike of the fracture azimuth were shown. The fracture height correlated with the thickness of many of the sand members. This allowed the operator to identify locations for future well placement for reservoir recovery optimization. Additionally, the mapping of the out-of-zonal fracture height between successive stages identified probable fault planes in the reservoir.

Cast History No. 2

Operator's Challenge:

This ArkLaTex area operator needed a better understanding of a reservoir to be hydraulically fractured for an infill drilling program in a major producing formation. The low permeability sandstone formations in this region are known to have extremely large lateral extent. The orientation of existing hydraulic fracture systems and their corresponding drainage patterns from existing well bores were not known prior to beginning this infill drilling program.

The Solution:

ExactFrac service was selected by the operator to monitor the hydraulic stimulation treatments for his program. Many times in cases such as this one, a pressure depleted region will have a lower stress than a region at virgin reservoir pressure.

Therefore, a hydraulic fracture will propagate toward the lower stress regions.

The Result:

The ExactFrac real-time display of the mapping of fracture propagation using micro-seismic techniques was able to identify fracture propagation toward a previously drained region of the reservoir by the mapping of asymmetrical fracture geometry. Identifying these features in near real time and the early termination of the treatment into a previously drained region resulted in a cost savings to the operator and provided necessary data for 3D reservoir modeling.

Case History No. 3

Operator's Challenge:

This operator was seeking answers for previous fracturing treatments that resulted in poorly stimulated zones.

The Solution:

After discussions with Halliburton, the operator elected to use the ExactFrac service to monitor hydraulic fracture propagation in a horizontal well. Seismic sensors were installed in a nearby vertical well for the monitoring. The completion design specified seven stages equally spaced from the toe to the heel of the horizontal section. External casing packers (ECP's) and ball-operated sliding sleeves were utilized for wellbore isolation and access to the formation.

The Result:

The real-time fracture monitoring indicated poor communication along the wellbore due to probable ECP-related issues. Microseismic events were detected in two different sands while fracturing through one sliding sleeve. The mapping of the fractures identified shorter than anticipated fracture half lengths due to the inadvertent simultaneous stimulation of two sands. Knowledge gained from the mapping allowed subsequent fracture treatments to attain improved production from fractures in the same formation.

Case History No. 4

Operators Challenge:

This national oil company needed to evaluate the effectiveness of its re-stimulation treatments in a horizontal well. The formation is a vugular carbonate in a mature basin.

The Solution:

ExactFrac service was recommended to the operator to monitor the re-fracturing treatments. The horizontal well was originally

completed with ball-operated sliding sleeves. Re-stimulation treatments generally result in less out-of-zonal fracture height than initial stimulation treatments due to production and associated pressure decline. The decline in reservoir pressure provides a favorable vertical stress profile which, in turn, can result in an increased fracture length on re-stimulation, thereby adding additional inflow.

The Result:

Compared to the large number of microseismic events created during initial fracture propagation, the re-stimulation treatments produced fewer detectable microseismic events. This was due to the existing fracture systems. In spite of the creation of fewer microseismic events, the ExactFrac system detected events near the tip of the previous fractures and determined the effectiveness of the re-stimulation treatment. The effectiveness of fluid diversion techniques was also confirmed by the mapping of events in the near wellbore region of the treatment well.