GRI-98/0250

Topical Report

Hydraulic Fracture Growth, Geometry and Far-Field Character Using Advanced Hydraulic Fracture Diagnostic Technologies in the C-Sand Interval: GRI/DOE Multi-Site Project

Prepared by:
Branagan & Associates, Inc.
Sandia National Laboratories

Prepared for:
Gas Research Institute
U.S. Department of Energy

Gas Research Institute

Drilling and Completion Technology Project Area

August 1998

1.0 EXECUTIVE SUMMARY

The Multi-Site, or M-Site, Project is a coordinated experiment plan to assess, develop, and validate hydraulic-fracture diagnostic and modeling technology. The M-Site project, which is jointly funded by Gas Research Institute (GRI) and the Department of Energy (DOE), is located in the Piceance Basin (Northwest Colorado) at the previously established Multi-Well Experiment (MWX) site. Specific objectives of the M-Site experimentation include the following:

- develop microseismic fracture diagnostics with a particular emphasis on fracture length;
- validate fracture diagnostic results using inclinometers and intersecting wells;
- provide the field information necessary to optimize and refine fracture models; and
- develop the foundation for a commercial fracture mapping service.

This report documents the results of fracture diagnostic experimentation conducted in the informally designated C-Sand interval of the upper Mesa Verde group. The C-Sand research represents the culmination of the four-year (1992 to 1996) research program conducted at the site. The primary site infrastructure used for the C-Sand experiments included a treatment well, one cased observation well for use with wireline-deployed receiver arrays, one fully instrumented monitoring well, a deviated well, and required surface support equipment. The Monitor Well was instrumented with 30 triaxial accelerometer receivers and 6 biaxial downhole tiltmeters for measuring microseisms and mechanical deformation, respectively. A wireline-run, multistation, accelerometer receiver array was deployed in the observation well for fracture mapping from a second offset location.

The deviated well used for the C-Sand experiments, termed Intersection Well No. 1C or IW-1C, was directionally drilled before performing any hydraulic fracture injections in the C Sand. The well was positioned such that it crossed the C Sand at 52° from vertical at a point approximately 300 ft from the treatment well along the predicted hydraulic fracture azimuth. The section through the C Sand was uncased. With this wellbore configuration, a series of six hydraulic fracture injections (1-C through 6-C) were designed to propagate a fracture towards, into, and through the IW-1C borehole.

In association with these fracture injections, the planned C-Sand experiments had the following objectives:

- verify that microseismically measured fracture length approximates mechanical length of the hydraulic fracture,
- assess the generation of multiple far-field fractures,
- assess the dynamic pressure in the hydraulic fracture using various fluids,
- determine the conductivity of unpropped and propped hydraulic fractures,
- assess microseismic imaging abilities using a treatment-well-deployed accelerometer array,
- assess fracture dimensions based on shear-wave extinction, and
- determine the effects of a propagating hydraulic fracture on generating variations in far-field stress.

The imaging data from the C-Sand tests were high quality and data analysis resulted in the following observations and conclusions:

- Microseismically imaged hydraulic fracture length was verified in Injection 2-C. Pressure in IW-1C increased when the hydraulic fracture made an initial connection to it, thereby providing a definitive value for fracture length at that particular time. The time of thii pressure increase corresponded precisely to when microseismic events were mapped as having advanced 300 ft to the IW-1C location. The fluid volume pumped at the time of intersection was 130 bbl.

- The stress variations associated with an approaching or passing hydraulic fracture were clearly evident using IW-1C pressure data. Bottomhole pressure measured in association with Injection 2-C began decreasing in the intersection well after injecting approximately 66 bbl. The pressure dropped a total of 4 to 6 psi before beginning to increase as the fracture passed the C-Sand lateral (at 130 bbl injected) and made an initial connection. A similar drop was observed in association with Injection 3-C; however, in this case, the pressure decrease began after 18 bbl had been injected. The subsequent pressure increase began after having injected 67 bbl. This rapid pressure response indicates that the fracture tip was reopening. These events indicated that fracture tip tensile effects are observable and distinguishable from other phenomena.

- After Injection 4-C was conducted, several newly formed fractures were observed in borehole image log data acquired in the C-Sand lateral. After Injection 6-C, up to 15 fracture strands were observed in the image data. The position of these fractures in the C-Sand lateral, in both cases, was just below the C-Sand interval. Thus, the calculated hydraulic fracture azimuth was N81°W which compares to an average of N74°W derived from the microseismic maps.

- The mapped injections exhibited interesting fracture growth characteristics including asymmetric fracture wing lengths, confined fracture height growth with linear-gel fluid and limited out-of-zone height growth with crosslinked gel fluid, asymmetric height growth, rapid lateral fracture extension with low-viscosity fluids, and complex fracture geometry including splays (perhaps activated faults) and possibly horizontal fracturing. This mapping effort leads to the conclusion that complicated hydraulic fracture growth is normal, at least in these complex fluvial reservoirs.

- Treatment-well monitoring of microseismic events was performed in association with Injection 5-C but did not yield interpretable data with regard to fracture growth or geometry.

- Shear-wave shadowing experimentation did not provide fracture geometry information generally because of a lack of observable s waves from an air gun source. However, additional examination of these data will be conducted to determine if further processing of the data can reveal the s waves or subtle changes in waves due to the fracture.

- Attempts were made to perform unpropped and propped fracture conductivity tests in the C Sand. After the fluid-only Injection 4-C, well-to-well pressure communications could be readily observed between MWX-2 and IW-1C; however, fluid flow between wells was impossible to establish. The Injection 6-C fracture clearly intersected the C-Sand lateral, as evidenced by the recovery of gel and proppant in the remote well, but results were similar to those for Injection 4-C. The conclusion was that some form of borehole obstruction and/or a poor well-to-frac connection probably exists at IW-1C, thereby preventing derivation of a true estimate of fracture conductivity.

- Fracture modeling was performed on all injections. Two modeling approaches were used: one which represented the best match to the pressure data (i.e., unconstrained approach), and the other in which matches were constrained to match microseismic dimensions by varying any of the available model parameters to obtain the history matches. Model parameters that were modified to force, when necessary, the model to fit microseismic geometries were leakoff factor (specifically, only after Injection 6-C to match the apparent higher leakoff) and volume factor to "adjust" fracture dimensions. The level of dilatant rock deformation (i.e., tip effects) was modified uniformly for all six injections, depending on the model being used, to match the levels of observed net pressure (although another parameter, such as Young's modulus, could have provided the same effect). In most cases, concurrent net-pressure matches and microseismic geometry matches can be attained by altering one or more of the default parameters in the dilatant and/or nondilatant models. However, it could not be determined when and how much to apply the different parameters if microseismic images were not available.

From an overall perspective, the A-, B- and C-Sand series of experiments conducted at the M-Site validated length, height, and azimuth imaged using the microseismic technique. This validation has set the stage for commercialization of wireline-deployed accelerometer arrays for mapping hydraulic fracture growth and geometry.