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An Interpretation of M-Site Hydraulic Fracture Diagnostic Results

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Abstract

Experiments at the GRI/DOE M-Site have shown that hydraulic fractures have a considerable degree of complexity that is difficult to account for using current understanding. Several of the key features are reviewed and an attempt is made to examine them relative to fracture mechanics, elasticity, and fluid-flow mechanisms. Key features include unexpected fracture containment, multiple fracture strands, secondary and T-shaped fracturing, large pressure drops down the fracture, significant differences in microseismically imaged geometry as a result of fluid-system changes, unexpectedly large residual width/deformation measurements after unpropped fracturing, large discrepancies in fracture area (and, thus, volume) between imaging and modeling results, evidence of complexities in proppant transport, and measurement of a clearly defined fracture closure pressure using a pressure independent technique.

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Microseismic and Deformation Imaging of Hydraulic Fracture Growth and Geometry in the C Sand Interval, GRI/DOE M-Site Project

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Abstract

Six hydraulic-fracture injections into a fluvial sandstone at a depth of 4300 ft were monitored with multi-level tri-axial seismic receivers in two wells and an inclinometer array in one well, resulting in maps of the growth and final geometry of each fracture injection. These diagnostic images show the progression of height and length growth with fluid volume, rate and viscosity. Complexities associated with shut downs and high treatment pressures can be observed. Validation of the seismic geometry was made with the inclinometers and diagnostic procedures in an intersecting well. Fracture information related to deformation, such as fracture closure pressure, residual widths, and final prop distribution, were obtained from the inclinometer data.

Introduction

Contrary to expectations based on simple models, hydraulic fracturing is proving to be a complex process that is still not adequately represented by theory. The reason for this is clear, as models assume that the earth is a homogeneous isotropic continuum when in fact the reservoirs which are fractured are highly discontinuous and variably anisotropic and heterogeneous. Since current models are incapable of dealing with this complexity in anything but an ad hoc manner, further understanding of hydraulic fracturing is not likely to progress very rapidly without an ability to measure, image, or observe fracturing processes under in situ reservoir conditions.

A glimpse at the complexity of fracturing in real reservoirs is now available from several cores through hydraulic fractures, from limited mineback experiments, and from various diagnostics. From these relatively few measurements, complex features such as multiple fracture strands, secondary fractures, T-shaped fractures, redirection of fracture orientation due to production, inefficient growth across bedding, complex proppant transport, and other unexpected features have been seen. From this limited sampling, one would conclude that the fracturing process is poorly represented by most models. However, it should also be stressed that the results found at the end of a treatment (e.g., as in a cored or mined-back fracture) may not be a good representation of the actual process during fracturing, since all complexities will be seen whether or not they had any significant effect on the mechanics of the process. Separating out irrelevant features is difficult using only post-fracture snapshots of the process.

For the reasons noted above, it is clear that the optimum diagnostic would provide a real-time continuous image of the fracture growth process. Currently, there is no envisioned technology for directly viewing the fracture, but some fracture parameters can be indirectly monitored using downhole seismic receivers and downhole inclinometers. The application of these two technologies in the C-sand interval at the M-Site facility is the subject of this paper.

M-Site

The M-Site field experiments, located at the previous Multiwell Experiment site in the Piceance basin of Colorado, are co-funded by the Gas Research Institute (GRI) and the US Department of Energy. Details of the M-Site layout and instrumentation are given in previous papers and are only briefly repeated here. The reservoirs undergoing testing are fluvial Mesaverde sand-shale sequences, so the technologies developed in this difficult environment are translatable to many other reservoirs. Results of previous tests are found in several papers and reports.

A plan view of the site is shown in Figure 1 and a schematic of the well, instrument, and sandstone layout are given in Figure 2.