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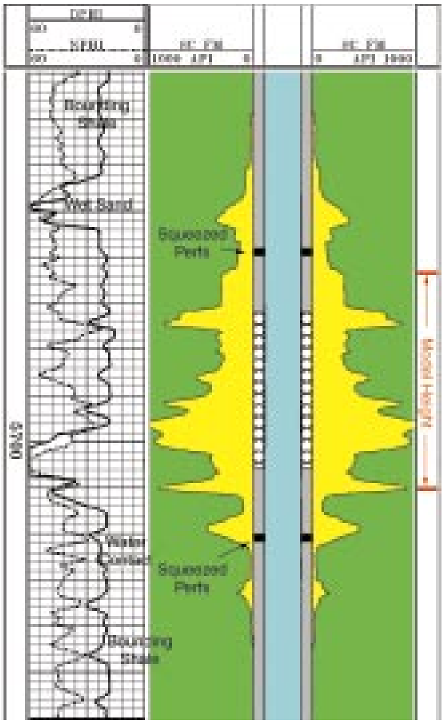
ProTechnology

3-D Frac Models: *Truth or Consequences?*

Industry surveys reveal that the two most widely used diagnostic tools for determining hydraulic fracturing effectiveness are fracture models and radioactive tracers followed distantly by technologies such as pressure buildups, microseismic imaging, and tiltmeters. Today, diagnostic tracers are used on about 300 fracturing procedures per month, or 15% of all fracturing jobs.

One of the greatest weaknesses of all 3-D fracturing models is that their numerical solutions are non-unique, that is, for the same set of input parameters, several different fracture geometry solutions are possible, all of which satisfy the constraints within a given model. As a result, the completion engineer is left holding a mixed bag of “solutions” and is forced to tweak input parameters to force an answer that matches common knowledge in the area.

For 3-D models to attain a higher confidence level as fracture geometry predictive tools, they must be accurately calibrated with reservoir-specific data such as rock elastic modulii, closure stress, fluid leakoff, pore pressure, layer permeabilities, porosity, etc. – a sometimes daunting and expensive undertaking. Without proper parametric calibration, the modeled geometry (even with pressure history matching as an input) is, at best, an educated guess and, at worst, misleading to the point of bypassing recoverable reserves or overestimating the slurry volume necessary to achieve a desired fracture length.



Many operators bridge the gap between low-confidence input data and more rigorous solutions from extensive reservoir property analysis by using tracers to establish key anchor points such as propped and fluid height at the wellbore, time-based proppant distribution, local proppant concentrations, and propped fracture widths. With tracer data augmented by rock property data from offsetting wells, the fracture modeler can calibrate his model and generate a more unique and correct solution for fracture geometry.

In this example an offshore Gulf of Mexico well was originally designed to be frac-packed. A water contact below and a water sand above the perforated pay interval led the operator to perform a traced minifrac job with the same borated crosslinked gel that would be used on the fracture pack. The SpectraScan Image clearly shows the fracture height growth to be greater than the model design; in fact, the growth is into the water-producing intervals. The fracture modeler recalibrated his model and determined that a lower-viscosity fluid would be required to avoid the water zones. A high-rate water pack was subsequently designed and pumped, and the zone has been producing sand-free and water-free for more than 6 months.

Many pitfalls await the unwary frac modeler who uses minimal or imprecise input parameters. Tracers are the most valuable diagnostic measurement available today to augment your numerical simulations.

An understanding of reservoir heterogeneities is critical in the design and operation of all secondary and tertiary flood projects. During injection operations, the injected fluid will flow preferentially into the high-permeability intervals and fractures. This type of fluid movement in the reservoir reduces sweep efficiency, increases lifting costs, and reduces oil recovery. The use of interwell tracers provides the only direct means of tracking the movement of the injected fluid in the reservoir, thereby allowing the identification of these reservoir heterogeneities. Once these heterogeneities are known, steps can be taken to minimize their negative effect on both operating costs and oil recovery.

The following example illustrates how interwell tracers were used to identify water channeling and to assist in the design of gel polymer treatments, which resulted in the addition of new reserves for a field under waterflood.

In mid-1992 a West Texas operator implemented a waterflood on a 280-acre lease producing from the San Andres formation. The San Andres has a gross thickness of approximately 350 feet. Core analysis indicates it is composed of dolomitized grainstones and packstones separated by laterally continuous shale intervals. The Upper San Andres is characterized by its intergranular porosity and eight producing intervals, whereas the Lower San Andres exhibits moldic porosity, with moderate natural fracturing, and only three producing intervals. Because of this difference in lithology, water injection into the San Andres was managed with the use of isolation packers and flow regulators as shown in Figure 1.

Within 6 months of initial water injection, lease production increased from an average rate of 225 BOPD to a rate of 645 BOPD. By the end of the first year, problems began to appear. Several wells began showing significant increases in water production, resulting in high fluid levels that could not be pumped down. In addition, the high H_2S content in the untreated injection water began deteriorating the flow regulators, resulting in an adverse change in the vertical distribution of the injected water.

The Use of Interwell Tracers as Diagnostic Tools in Water-flood Can Assist in the Addition of New Low-Cost Reserves

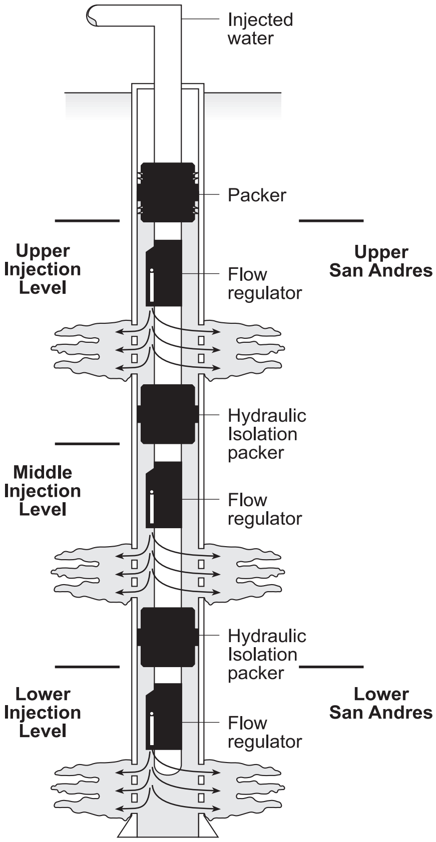


Figure 1 — Injection well configuration

Therefore, a two-phase interwell tracer program was developed to assist in diagnosing these problems. The objective of the Phase I program was to identify which injection and producing wells were in communication. The Phase II program was then designed to determine which of the 11 San Andres intervals under waterflood were responsible for the communication. Two pattern areas on the subject lease were selected for the interwell tracer program.

In February 1993 the Phase I interwell tracer program was implemented. The program consisted of injecting tritiated water (HT0) into WIW Nos. 33 and 40, and ammonium thiocyanate (CNS^-) into WIW Nos. 38 and 39. The results of the Phase I program are shown in Figure 2. Tracer breakthrough occurred in seven producing wells with breakthrough times ranging from less than 1 day to 15 days. These results were used in the design of the Phase II interwell tracer program.

To prepare for Phase II, the original injection intervals were again isolated in WIW Nos. 33, 38, and 40. This allowed for the injection of a different interwell tracer into each of the three Injection Intervals in the San Andres formation. During Phase II, ethanol and ammonium thiocyanate were injected into the Upper Injection Interval, acetone and amino-g were injected into the Middle Injection Interval, and tritiated water and ammonium nitrate ($N0_3^-$) were injected into the

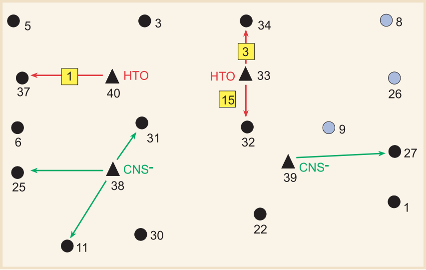


Figure 2 — Results of Phase I Tracer program

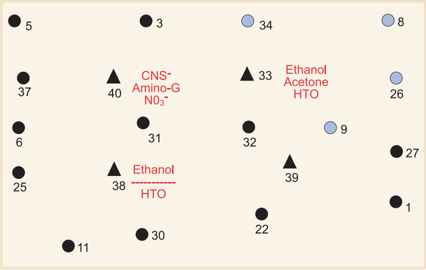


Figure 3 — Phase II Tracer program

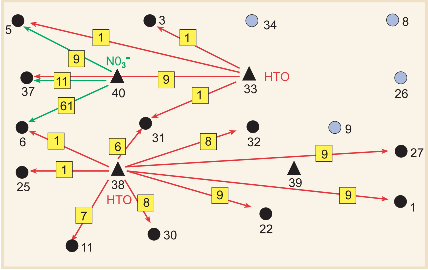


Figure 4 — Results of Phase II Tracer program

Lower Injection Interval. The placement of these interwell tracers are shown in Figure 3. Note that no tracers were injected into WIW No. 39 during the Phase II program.

The results of the Phase II program are illustrated in Figure 4. Rapid breakthrough occurred in the Lower Injection Interval of the San Andres formation where the tritiated water and ammonium nitrate were used. The tracers injected into the Upper Injection Interval did not show up at any of the producing wells in the pattern area. Tracer breakthrough occurred in the Middle Injection Interval in only one well in the two pattern areas.

The two interwell tracers programs indicated not only that channeling occurred between injectors and producers in both pattern areas investigated, but that the majority of the channeling occurred in the Lower Injection Interval. This information allowed the design of polymer gel treatments for the injection wells to improve areal sweep efficiency in the Lower Injection Interval and to provide improved vertical conformance over all 11 productive intervals in the San Andres formation.

In each of the four injection wells in the two pattern areas, the Lower Injection Interval was isolated and an aqueous acrylamide polymer solution was pumped along with a chromic triacetate crosslinker. The total pumped volumes ranged from 5,200 bbl to 8,100 bbl of the polymer solution, with the polymer concentration increasing during the treatments from 3,000 ppm to 8,500 ppm.

Ten of the offset producing wells began to display increases in oil production within a month of the pumping of the injection well gel polymer treatments. The peak response from the offset producing wells was an incremental 125 BOPD with no increase in water production. The sustained response over a period of 18 months was an incremental 75 BOPD. Incremental reserves, resulting from the interwell tracer program and polymer gel treatments, were calculated at 200 MBO for a cost of approximately $3.00 per STBO.

In summary, the use of interwell tracers identified and confirmed that communication existed between many of the injectors and producers in the waterflood area. In addition, the second phase of the interwell tracer program allowed the identification of the vertical interval responsible for the majority of the communication. This information was critical in the development of the resulting polymer gel treatments. Without the Phase II program results, the gel treatments would have been designed based on the entire San Andres interval thickness of 350 feet. Instead, the gel treatment designs used the Lower Injection Interval thickness of approximately 50 feet, resulting in a significant savings in the cost of the gel treatments. The combination of using interwell tracers and gel treatments not only increased production on the lease, but also allowed the addition of approximately 200 MBO of reserves at a cost just over $3.00 per STBO.

Did You Know?

ProTechnics patented Zero Wash® tracers have the highest compressive strength (8,000 psi) of all modern tracer particulates. This eliminates crushing and minimizes residual contamination caused by abrasion.

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