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Case Histories of Successful Stimulation Fluid Dispersion Using Pressure Pulsation Technology

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Abstract

This paper presents the results of field testing a pressure pulsation tool and technology for deeper invasion and dispersion of stimulation fluid without the use of mechanical or non-mechanical diversions. The mechanism involves generation of porosity dilation waves and pressure effects. The porosity dilation effect creates pressure waves that force fluids into normally unoccupied pore spaces. This effect is attributed more to fluid wave propagation and pore dilation than rock movement.

This paper discusses pressure pulsation technology (PPT) theory and presents field validation through pre- and post-production numbers and Iridium and Scandium tracer analysis.

Introduction

A field trial of the PPT^2 stimulation tool was conducted on two wells in a field, 20 miles southwest of Bakersfield, California. In particular, the field trials were conducted on one shallow oil Etchegoin sandstone producer and two Monterey shale producers. The shale formation producers had seen tremendous success with the recent development of high volume acid stimulation and were the target of acid stimulation improvement. For the purpose of investigating the effectiveness of the PPT stimulation tool, this analysis and discussion will focus on the two shale candidates.

Previous acid stimulation methods for shale producers include coiled tubing placement, mechanical diversion, and non-mechanical (chemical) diversion. Previous stimulation results indicate that diverting stimulant fluid away from highly conductive natural fractures and dolomite streaks is important in successfully acidizing a well. If the stimulation work does not focus across the pay interval, past experience indicates the possibility of stimulation fluid being thieved in smaller areas where either natural fractures or dolomitic episodes exist.

A study conducted in 2005 using mechanical diversion methods yielded longer sustained production and incremental production 10 boe/d higher than coiled tubing placement methods conducted in prior years. Therefore, the expectation for the PPT trial was to (1) achieve dispersion throughout the pay interval, (2) reduce pump/trouble time by eliminating screwed tubing and packer setting, (3) lower costs by reducing tool rental duration and overall stimulation time, and (4) improve production by deeper invasion and dispersion of stimulation fluid.

Theory and Applications of Pressure Pulsation Technology

Porosity—the size of the pore spaces within rocks and soils—has been well established as a major contributor to the ability of fluids to flow in the ground. Permeability—the efficiency of fluid flow through interconnected pore pathways—is considered the greatest obstacle to overall fluid injection and fluid recovery. If pore space size and pore interconnectivity govern fluid flow during liquid extraction, as it does in oil production, then those same characteristics also govern how well a fluid can be injected and distributed into the ground. Therefore, porosity and permeability control both fluid extraction and fluid injection, as illustrated in Fig. 1.

As an example, imagine that water is going to be injected into the ground under constant pressure for the purpose of establishing a drive mechanism during secondary oil recovery. This is referred to as "static water injection". Natural events have already formed a system of pores and pore interconnectivity in the formation. This system can be somewhat altered by processes such as fracturing or tectonic activity (earthquakes), but all things being equal, this system is pre-determined. The flow rate and distribution of the water injected into the rock or soil is dominated by that pre-determined system. The water will take the path of least resistance through the formation, which can not be altered, by increasing injection pressure alone. Furthermore, it is almost technically impractical for the water to be distributed outside the path of least resistance. The path of least resistance dominates because pore space size and pore interconnectivity remain the same throughout the entire process. In the oil industry, the efficacy of how injected liquid is distributed in a formation is termed "sweep efficiency" or "displacement efficiency."

Now assume water is injected into the ground under constant pressure for secondary oil recovery, but assume an intermittent dynamic force is superimposed on that process. This is termed "dynamic enhancement" or "dynamic flow." The magnitude and duration of the dynamic force is calculable for every given rock or soil. PPT intermittently changes both the size of the pore space and pore interconnectivity through the applied dynamic force (see Fig. 2). How is this accomplished?

PPT relies on the elastic properties of rocks and soils. When a fluid pulse is applied through the injected liquid, it dilates the pore space through an elastic response. This in turn causes not only the pre-determined pore network to increase in size and interconnectivity but also opens up additional pore spaces to liquid flow. Therefore, PPT governs how flow occurs because it overcomes the path of least resistance. The result is greater sweep or displacement efficiency. This represents greater overall productivity gains during secondary oil recovery processes or when treatment liquids, such as acids and surfactants, are used on single wells.

Molecular diffusion, pore scale dispersion and megascale viscous fingering represent processes associated with the mixing of the fluids at the molecular scale, the macroscale (pore scale), and the megascale, respectively. Diffusion represents the mixing of fluids at the molecular scale through molecular diffusion of the phases. Dispersion occurs as a result of the adverse viscosity ratio, a variation in flow velocities within pores, and pore and throat size distribution, all of which cause the fluids to mix at the pore scale but remain distinct phases at the molecular scale. Viscous fingering is caused by an unstable mobility ratio between the displacing and the displaced phases, resulting in megascopic channels of the displacing phase passing through the displaced phase, as shown in Fig 3. The primary objectives of PPT are to enhance fluid injection, sweep efficiency, and dispersion through pore scale dilation.

Technical Description of the PPT Simulation Tool

The PPT stimulation tool is a downhole pressure pulse generator that provides enhanced fluid placement and helps improve production through fluid wave generation and pore-scale dispersion. PPT is licensed from a third party.[2] Improved production over standard pump-and-treat techniques is achieved through the following:

- Deeper placement of chemical treatments for enhanced results.
- Pinpoint placement of chemical treatments without zonal isolation.
- New permeability flow paths created through a combination of forced fluid injection and pore-scale dispersion.

PPT stimulation service uses downhole pulsing as shown in Fig. 4 and is based on the following principles:

- Large-amplitude, low-frequency pulsing enhances the flow of fluids in porous media.
- The mechanism involves generation of porosity dilation waves and pressure effects.
- The porosity dilation effect creates pressure waves that force fluids into normally unoccupied pore spaces. This effect is attributed more to fluid wave propagation and pore dilation than rock movement.

The PPT stimulation tool provides a safe, reliable, and effective means for enhancing fluid injection with deeper penetration into the reservoir matrix. A cost-saving feature of this tool is its ability to run on coiled tubing. The system can be used for many applications. These include, but are not limited to the following:

- Stimulation treatments
- Screen or perforation cleaning
- Remedial treatments
- Sand control
- Horizontal wells

Innovative Aspects

The PPT stimulation tool is designed with configurable inserts for creation of desired pressure pulse forms, as shown in Fig. 5. With the configurable inserts and controlled rotational speed using the gear reduction system, idealized pressure waves (Figs. 6 and 7) can be generated by a flow area-to-rotational speed relationship. Environmental impact is minimized because PPT reduces the volume of chemicals required compared to conventional methods. Innovative aspects include:

- Through-tubing applications
- Configurable inserts
- One-trip, multi-stage chemical injection capability
- Side-jets that maximize fluid injectivity

Field Trial Results and Analysis

A vertical and a horizontal well were selected for the PPT stimulation tool trial. Both wells were cased, cemented, and perforated in the Monterey shale formation with a mixture of quartz and CT-phase porcelanite. Both wells had natural fractures and dolomitic episodes that posed potential problems for stimulation fluids. The wells were treated with 1 bbl/ft of 15% Fe pad acid followed by 135 gal/ft of 12% HCl/3% HF (mud) acid and then displaced with 10 gal/ft of clay-stabilizing fluid. The acid recipe and volumes were chosen based on their past successes in the shale, while the PPT stimulation tool was selected for reasons discussed previously. Furthermore, both Fe and mud acids were tagged with 0.50 mCi/1,000 gal of Ir-192 L.D. Zero Wash (Iridium) and 0.36 mCi/1,000 gal of Sc-46 L.D. Zero Wash (Scandium) radioactive tracers, respectively, for the trial to determine whether dispersion and deeper penetration were achieved.

The PPT tool was placed at the end of the 1-¼ in. coiled tubing, and the tool was run across the perforated interval throughout the stimulation work to further ensure even dispersion. Figs. 8 and 9 indicate injectivity improvement for Well 1 and Figs. 10 and 11 indicate injectivity improvement for Well 2. While acid was being pumped, both wells exhibited injectivity improvement during acidizing, but the results could not be clearly credited to the PPT tool because acid could have achieved the desired effect (lowering the fluid discharge pressure while maintaining the fluid rate to indicate skin removal). The shallow oil sand well that was acidized with the PPT tool also exhibited the lowering pressure throughout the job while the acid was pumped, but again this could not clearly be credited to either the acid or the tool, alone, for the success. Therefore, the tagging of the acid streams with Iridium and Scandium and investigation with a spectrum-type logging software allowed for some conclusive statements about the diversion capability of the tool.

The spectrum-type logging software that was run after placement of the stimulation fluid was used to determine whether the PPT tool was successful in dispersing acid. Figs. 12 and 13 show the software logs for both wells compared to openhole logs. In both presentations, the two wells indicate that both Fe acid and the mud acids were dispersed throughout the wellbore and also indicate deep penetration over portions of the wellbore. Previous investigation work after stimulating bullhead (i.e. open ended coiled tubing) indicated the majority of stimulation fluid exiting out of a very short pay zone, typically where a fracture or dolomite episode occurred. Therefore, the PPT tool did demonstrate dispersion and deep invasion.

Treatment Analysis

A third-party analysis from each well is given in the following sections.[1]

Well 1

1. There were four major areas of activity on this log, namely: A) a spikey area from approximately 6,830 ft out to logger's TD at 7,009 ft; B) a high count rate area from approximately 6,228 ft out to 6,771 ft; C) a low count rate area from approximately 5,795 ft out to 6,183 ft; and D) an inside-the-casing accumulation of traced material from approximately 5,399 ft out to 5,603 ft.
2. The spikey area from approximately 6,830 ft out to logger's TD at 7,009 ft might represent downward-channeling acid that entered higher a porosity/natural fracture/washout streak, thus creating a spikey profile. These spikes did not appear to be perforation specific.
3. The high count rate area from approximately 6,228 ft out to 6,771 ft appeared to represent a significant volume of traced acid being retained in the near-wellbore area from poorer penetration out into the reservoir rock. The poorer acid penetration across the lower portion of this zone likely contributed to the downward channeling of both Ir-192 traced 15% Fe acid, as well as the Sc-46 traced 12% HCl/3% HF acid.
4. The low count rate from approximately 5,795 ft out to 6,183 ft likely represented substantial acid displacement out away from the near-wellbore area. This area would have thus experienced deeper penetration of both the Ir-192 traced 15% Fe acid and the Sc-46 traced 12% HCl/3% HF acid.
5. The inside-the-casing accumulation of traced material from approximately 5,399 ft out to 5,603 ft appeared to represent traced material residing in an acute angularity section of the liner.

Well 2

1. The large, lower perforated interval at 6,117–6,208 ft exhibited moderate, near-wellbore placement of Ir-192 traced 15% Fe acid from approximately 6,117 ft down to logger's total depth (TD) at 6,220 ft. This same perforated interval exhibited substantial near-wellbore placement of Sc-46 traced 12% HCl/3% HF acid from approximately 6,115 ft down to logger's TD at 6,220 ft.

2. The substantially lower Ir-192 traced 15% Fe acid followed by somewhat lower Sc-46 traced 12% HCl/3% HF acid observed from approximately 6,117 ft down to 6,155 ft suggests that there may have been somewhat deeper penetration of the acid across this upper portion of the large, lower perforated interval.
3. The small, upper perforated interval at 6,092 ft to 6,099 ft appeared to remain unstimulated with just a trace of radioactivity likely due to a very small quantity of radioactive material being washed into the perforation tunnels or possibly because of the presence of small quantity of naturally occurring radioactive material (NORM).
4. There is evidence of a modest quantity of traced material inside the casing, as demonstrated by the scattered uphole spikes on the total gamma ray track (green and black curves) and by the presence of the traced material that computed inside from approximately 6,144 ft down to logger's TD at 6,220 ft.
5. Overall, the large, lower perforated interval appeared to have been adequately treated, while the small, upper perforated interval appeared to remain unstimulated.

Conclusions

With any new tool going through a field trial, there are always design challenges that require correction. The PPT tool is not an exception to this rule. The field trial on the two shale wells went relatively smooth, but both the tool's limitations and the effectiveness of the tool were discovered as a result. The limiting factors for these two wells were pump rate, downhole survival time, and hydraulic displacement. The PPT tool used was limited to 0.7 bbls/min, so pumping approximately 50,000 gallons of stimulation fluid was a challenge. To further complicate the situation, the tool exhibited an 8-hour limitation, but this could be attributed to the tool going through the development phase. Lastly, the software log did show some deep invasion caused by the PPT tool, but other jobs are pumped at typical pressures near the fracture gradient which was impossible for the PPT tool to achieve. The PPT tool did demonstrate dispersion and relatively deep invasion, but it did not reduce job time because the slower pump rate off-set any time saved by not having to make connections. The cost savings can not be fully evaluated at this time because the trial phase of the tool and the production response is moderate compared to other wells stimulated, but this might be a result of candidate selection; therefore, the tool can not be faulted on production alone.

As a result of conclusions gained from this field trial study, a 2.88-in. tool capable of higher flow rates, longer survival time, and higher pressures has since been developed.

Additional wells in the area along with wells in Oklahoma & British Columbia have since been stimulated with the 1.75-in. tool with post production increases ranging from 3 to 11 fold.

References

1. Core Lab; Robert Woodroof, Jr, Technical Manager.
2. PPT, now referred to as the Powerwave Process, is a licensed technology of Wavefront Energy and Environmental Services, Inc.

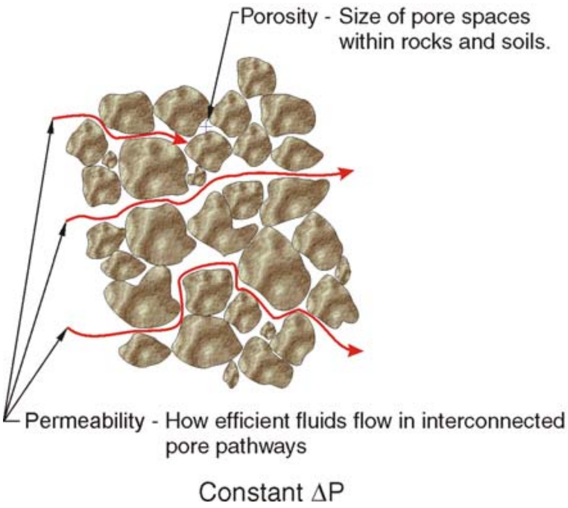

Fig. 1—The porosity of rock and soil determines how well fluids will travel through the formation.

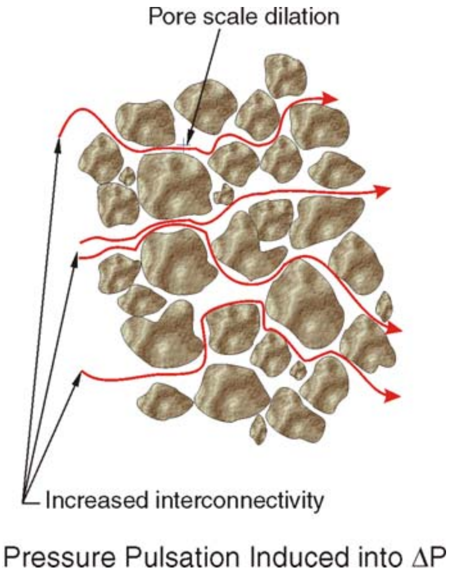

Fig. 2—Pore scale dilation increases interconnectivity in the formation.

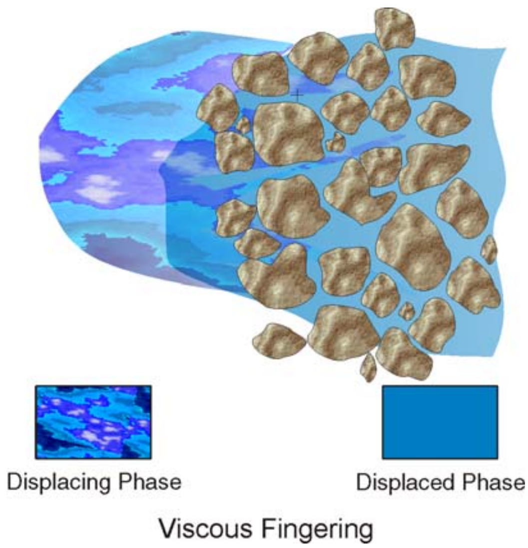

Fig. 3—An increase in the porosity and permeability of the formation results in viscous fingering.

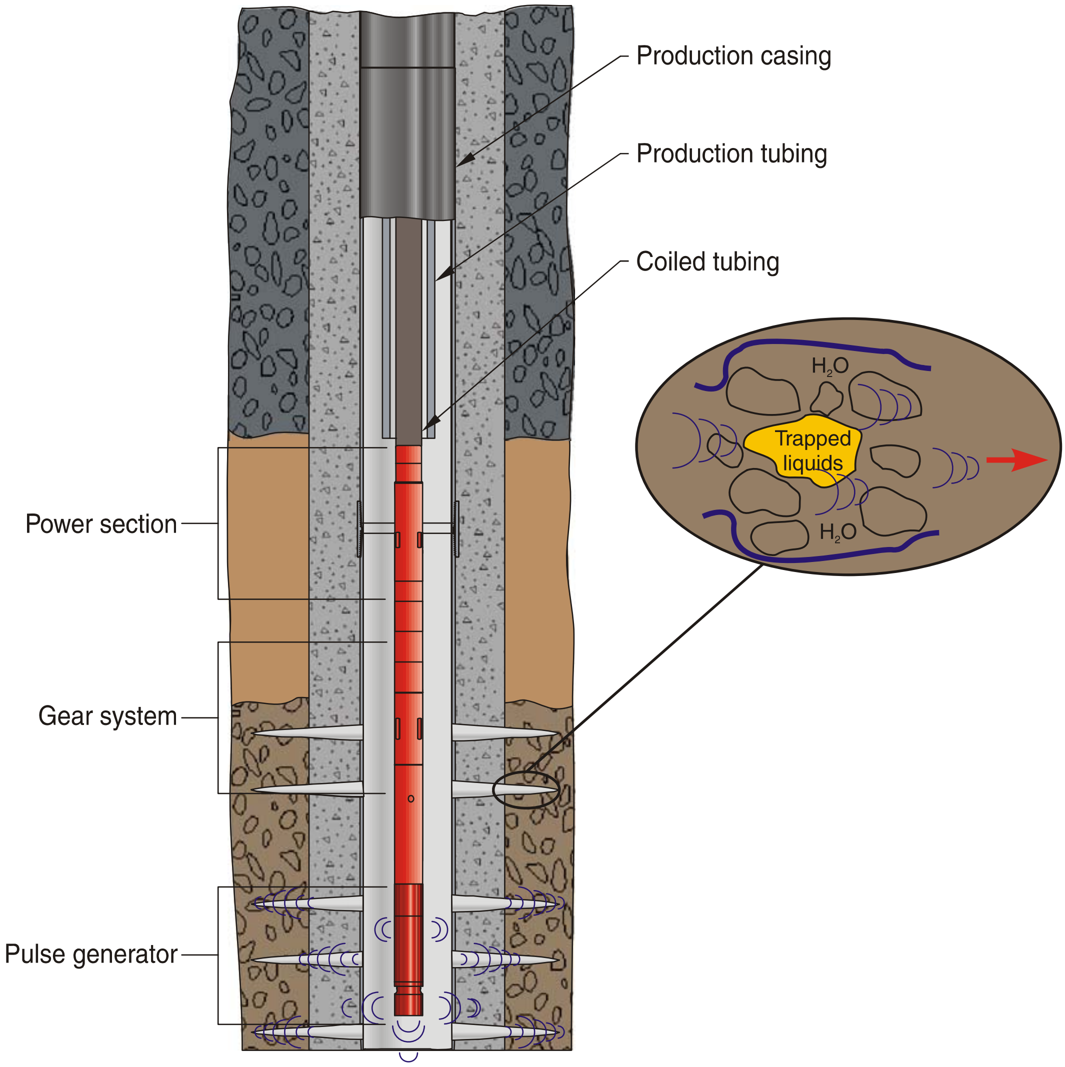

Fig. 4—The PPT stimulation tool uses downhole pulsing to dilate pores and increase porosity deeper into the formation.

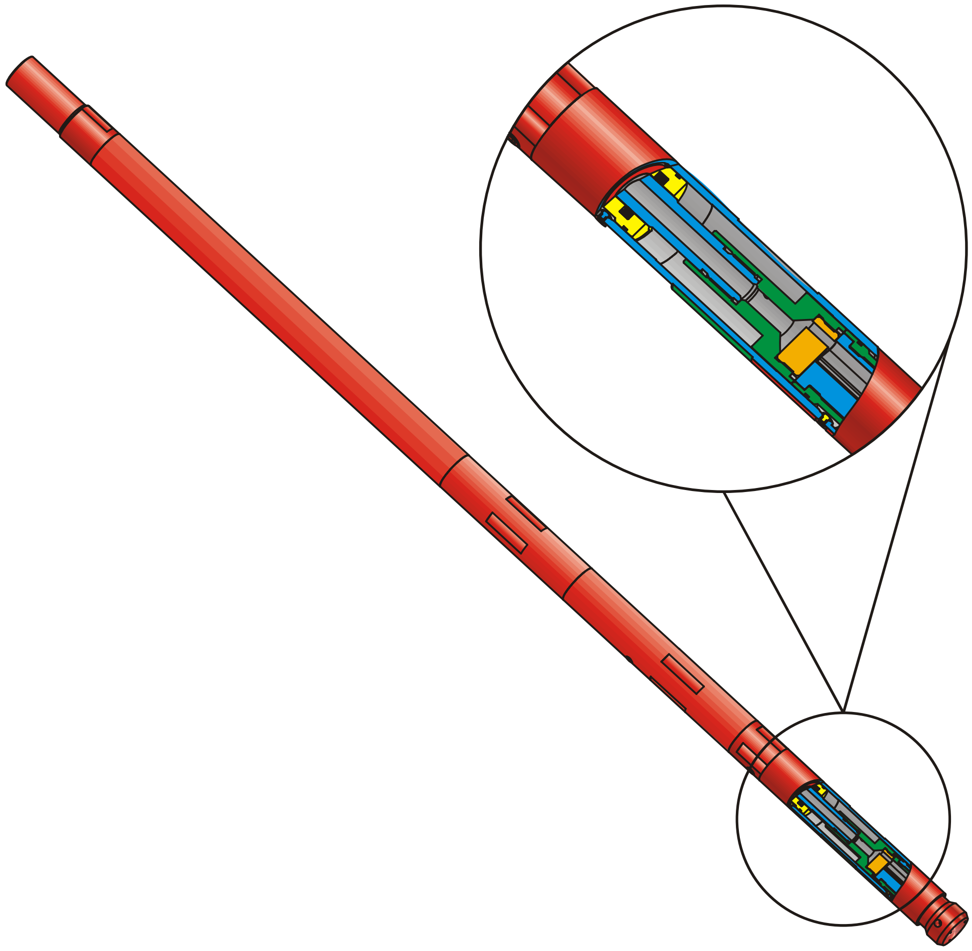

Fig. 5—PPT tool ISO.

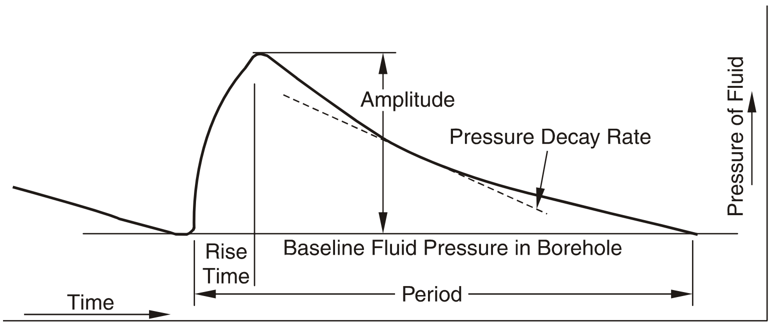

Fig. 6—Experience has shown that pore dilation and fluid movement can be best accomplished with a pressure wave as shown in the top idealized wave form.

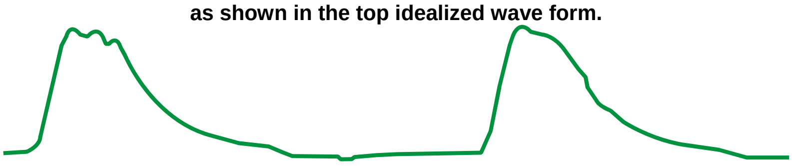

Fig. 7—Actual pressure waves generated by PPT stimulation tool.

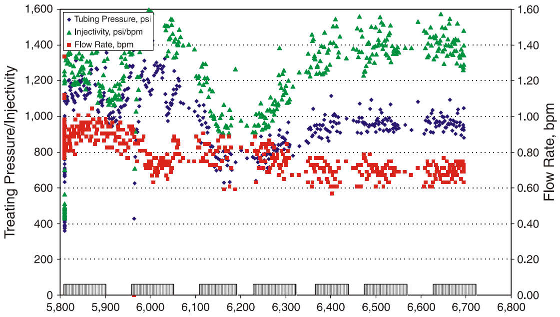

Fig. 8—Well 1 stimulation during first pass.

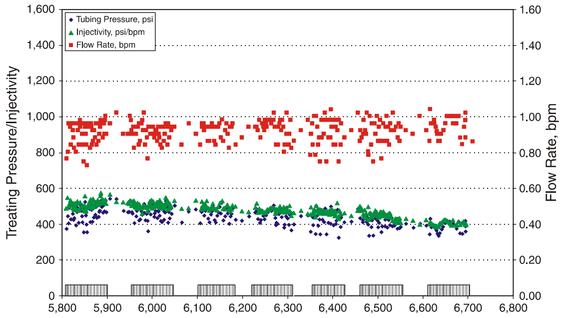

Fig. 9—Well 1 stimulation during last pass.

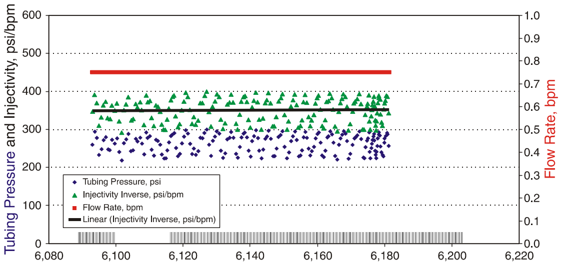

Fig. 10—Well 2 stimulation during first pass.

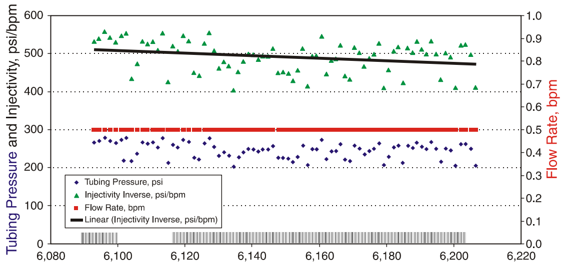

Fig. 11—Well 2 stimulation during last pass.

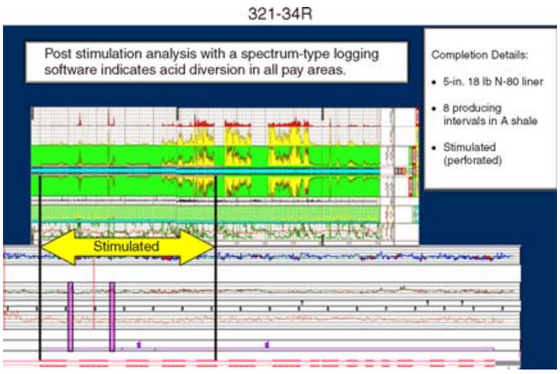

Fig. 12—Well 1 spectrum-type logging software analysis.

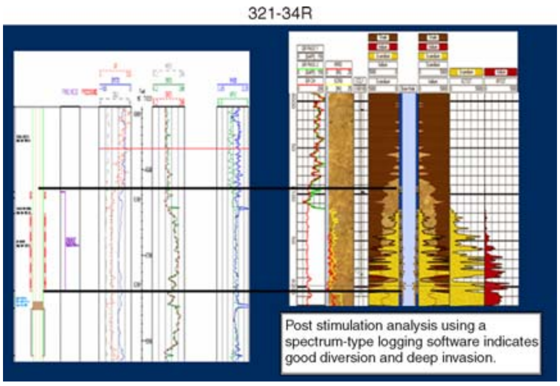

Fig. 13—Well 2 spectrum-type logging software analysis.