

# E&P

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## Stimulation

*Diagnostics close loop  
in shales*

## Diagnostics close loop in shales

Best practices result from engineering decisions guided by completion diagnostic measurements.

### AUTHOR

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In active, unconventional shale plays such as the Barnett in North Texas, success often depends on a sophisticated process of fine-tuning the completion process. This iterative process first determines reservoir characteristics, engineers a completion procedure and then measures the results. By understanding how the reservoir responds to the stimulation treatment, completion designs and even field development plans can be improved.

### Unconventional completions

Completion technology has evolved a great deal as the industry has shifted from conventional to unconventional prospects. Multizone and horizontal completions have fundamentally altered well economics.

Low- and no-polymer fluid systems, high-temperature polymers and other exotic fluid and breaker systems now allow careful matching of completion materials to formation characteristics. Proppants of various densities and strengths improve transport and conductivity in the most rigorous applications.

Fracture modeling and simulation have made equally impressive strides. Early 2-D frac models were first enhanced with pseudo 3-D models, which are now being challenged by planar 3-D grid-oriented models that more accurately represent rock shear decoupling, heterogeneous formations, fluid flow and proppant transport in the fracture.

These fine-tuned treatment systems and frac models are applied using two critical capabilities — better characterization of the reservoir prior to stimulation and better diagnostics after the fact.

### Diagnostics near and far

The growing ability to understand the reservoir before and after stimulation is the enabling technology for success in

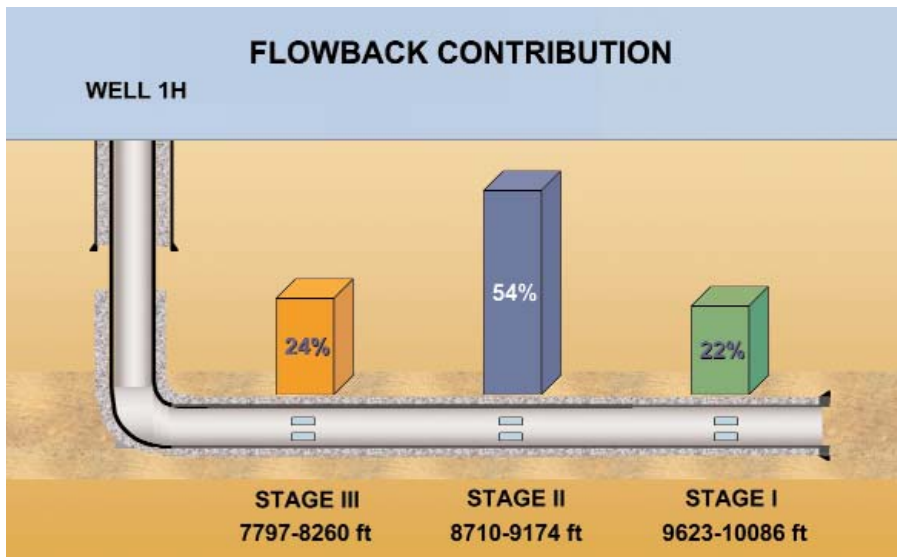


Figure 1. Flowback contribution from each stage was measured over seven weeks. (Images courtesy of ProTechnics)

many unconventional reservoirs. Two forms of post-treatment completion diagnostics provide unique perspectives on how the reservoir responds to a hydraulic fracture treatment: far field and near well bore.

Far-field diagnostics map fracture growth at a distance from the well bore by detecting microseismic events or minute tilting of the earth. Chemical tracers are used to selectively trace stimulation fluids to determine fracture communication with offset wells.

Near-wellbore diagnostics measure the quality and placement of the stimulation using solid isotope tracers in conjunction with spectral gamma ray tools. Production logging tools identify the productivity or success of each stimulation interval. In these applications, uniquely identifiable tracer particles are introduced to the stimulation proppants in very small amounts and pumped into the hydraulic fracture. Images of tracer placement measure such results as proppant placement, fracture height, mechanical integrity and most importantly, connectivity to the well bore. Chemical tracers injected with the stimulation fluid also provide near-wellbore diagnostics, including stage clean-up from measurement of flowback fluid samples.

### Near- and between-wellbore diagnostics

In unconventional shales, direct measurements achieved with near-wellbore diagnostic systems are used to calibrate frac models and determine zonal stimulation effectiveness, fracture containment, and refrac opportunities. Chemical tracers are being used to diagnose stimulation fluid cleanup, characterize multizone and horizontal stage flow-back and communication between the treatment well and offset producers.

Isotope and chemical tracing services provided by ProTechnics combined with field logging services and laboratory analysis are allowing a much more thorough understanding of hydraulic fracturing performance. With near-wellbore diagnostics, fracture geometries are being understood like never before. Frac height, for instance, was once considered to grow more or less unrestricted. We now know that height-contained fractures are very common and short, effective frac lengths are often the result of sub-optimal fracture cleanup. Understanding this has allowed engineers to develop more effective frac designs.

### Barnett Shale advances

The Barnett Shale got off to a slow start.

Only 100 wells were drilled in the 12 years following the first in 1981. In those days, economic and technical limitations were overwhelmed by the difficulty of producing from the .00007 to .005 md formation.

In the last 12 years, more than 4,000 wells have been drilled. Much of this activity is due to the success of water-frac stimulations, which in turn owe much to the optimization of stimulation efforts guided by both near-wellbore and far-field completion diagnostics.

Near-wellbore diagnostics have played a role in the development of the Barnett Shale from early conventional completions in vertical well bores to current horizontal completions. More than 500 wells for 35 operators have been traced by ProTechnics to provide unique insights into how the formation responds to hydraulic fracturing. Direct measurements are helping optimize well spacing, improve development plans, evaluate lateral cleanup, modify completion strategies and diagnose production and stimulation anomalies.

In early vertical wells, isotope tracer imaging was used to determine fracture containment, proppant placement, and refrac effectiveness. When the Barnett Shale's first commercial horizontal well was drilled in 2002, operators began to bolster this information with chemical tracer diagnostics to address new challenges being posed by the completions.

Operators wanted to know:

- Was the entire lateral being treated with various staging techniques?
- Were multistage, uncemented horizontal completions a viable option?
- What should the optimum lateral length be to ensure early stage cleanup?
- Does fracture interference affect offset wells?

In recent applications, surveillance tracing is being used to trace proppant in each stage with a unique isotope. When performance or stimulation issues warrant, the well is imaged to diagnose cement and casing integrity problems, production anomalies and completion effectiveness.

Table 1. Unique chemical and isotope tracers were pumped at each stage to precisely measure completion results.

STAGE	VOL (LB PROPPANT)	SPECTRASTIM TRACER	VOLUME	SPECTRACHEM TRACER
1	729,500	220 mCi Sc-46 ZW	1,830 M gal	CFT 1000
2	723,000	217 mCi Sb-124 ZW	1,850 M gal	CFT 2100
3	724,000	220 mCi Ir-192 ZW	850,000 gal 944,500 gal	CFT 1900 CFT 1200

Completion diagnostics are also being used to optimize perforation placement and evaluate multistage completions. Isotope tracer images clearly illustrate that stress diversion between stages makes multistage, uncemented completions an option in certain areas. In addition, diagnostic tools highlight refrac opportunities and show the value of cemented horizontal sections to future restimulations.

### Cleanup and communication

On a recent Barnett Shale project, chemical tracer diagnostics were used to evaluate the relative cleanup efficiency and treatment well communication with offset producers on a three-stage horizontal completion. Traced flowback samples were obtained on the treatment well and 12 offset wells.

All three treatment stages were pumped and traced (Table 1). Post-treatment diagnostics showed the entire lateral was effectively stimulated. Figure

1 shows the total flowback contribution for each stage over the 7-week sampling period. More than 50% of the sampled fluid came from Stage 2 while the remaining fluid was equally recovered from Stage 1 and Stage 3. This shows reasonable recoveries from all three stages when compared to other chemically traced Barnett wells.

The unique aspect of these data is that Stage 2 is the most dominant stage in terms of flowback contribution and communication with offset wells (Figure 2). Typically, the last stage pumped dominates the early fluid recoveries and then the cleanup increases over time for the earlier stages. However, there have been several chemically traced wells that have shown no flowback or very poor flowback from the early stages. This has caused several operators to reevaluate their completion techniques and cleanup procedures used on long laterals.

The 12 offset wells were analyzed for potential fracture fluid interference. The analysis showed five offset wells had fracture communication with the treatment well. Two of the five had fracture interference during all three stimulation stages

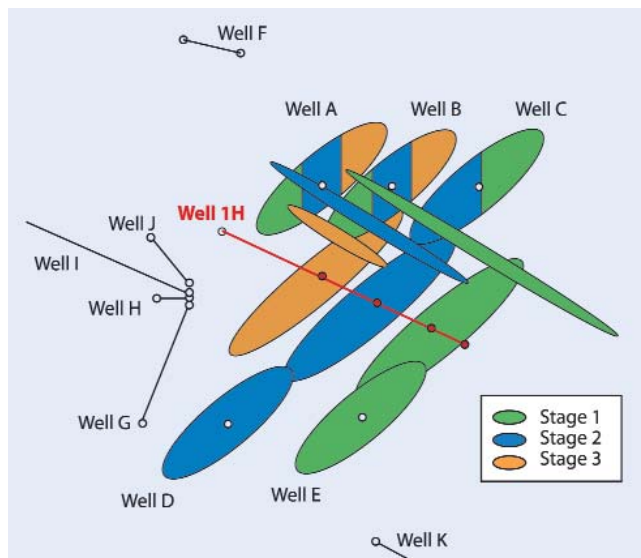


Figure 2. In addition to the highest flowback contribution, Stage 2 also dominates in communication with offset wells.

### Summary

Success in many of today's unconventional shale plays depends on an iterative process to fine-tune the completion design. The process of evaluating the reservoir characteristics and engineering a completion procedure is guided by completion diagnostic measurements. This process is being successfully applied to individual well designs and field development plans. **ENR**

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The Completion Diagnostics Company

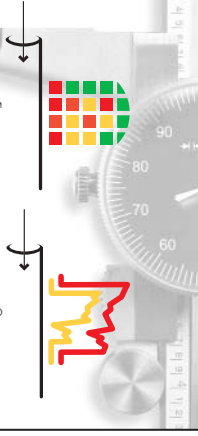
# Fracture height?

With ProTechnics patented tracer and imaging services you can directly measure:

- Fracture height
- Proppant distribution
- Wellbore connectivity
- Staging efficiency
- Zonal coverage
- Limited entry

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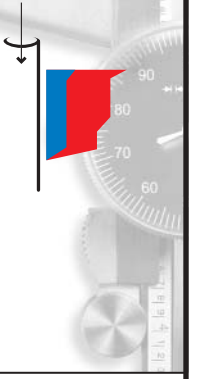
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# Fracture performance?

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- Wellbore connectivity
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- Water production problems
- Stage production contribution
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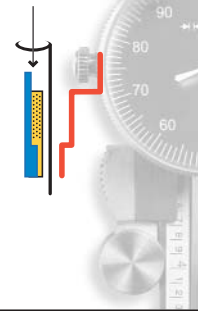
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- Long-interval pack coverage
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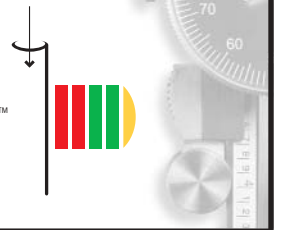
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# Fracture cleanup?

With ProTechnics patented chemical analysis you can directly measure:

- Frac fluid cleanup/flowback efficiency
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- Flow through bridge plug assurance
- Breaker efficiency
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