Pinnacle

NEWSLETTER Summer 2004

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UP FRONT WITH CHRIS WRIGHT

Two years with gas prices north of $4.00 has produced today's very robust industry activity level. As I've said before, the rig count may be rising but the quality of reservoirs being developed is not. What we can raise, however, is the quality of our drilling, completion, and stimulation engineering. Pinnacle is working very hard to enhance our fracture mapping, engineering, and modeling technologies. We are also expanding our service delivery capabilities to meet rapidly growing demand. This newsletter concludes with introductions to some of the newest Pinnacle team members.

The Bossier Sand Case Study at right illustrates yet again that fracture optimization is highly environment specific. Reservoir specifics—layer interfaces, fault presence, stress state, as well as the more obvious permeability and pay thickness—dictate what fracturing strategy best applies. Anadarko and Pinnacle have worked together to significantly enhance Bossier sand production economics.

This Newsletter's Tech Update begins a two part series on a subject near and dear to my heart: quantifying the uncertainty in tilt fracture mapping results. When I first pushed the concept of fracture mapping with precision tiltmeters most people simply thought that I was crazy. Some still do, but the number is shrinking! Quantifying fracture orientation uncertainty from surface tilt mapping is actually relatively straightforward. However, it involves Monte Carlo analysis of nanoradian uncertainties on a process occurring a mile or so underground. Hence it rarely seemed straightforward to our first customers. My case was helped tremendously by numerous direct confirmations of tilt mapping results from minebacks in coalseam fracs, core-throughs by Mobil in Lost Hills and an industry consortium at Mounds, offset wellbore intersections, and even surface breaches. Direct observations that confirmed that tilt mapping results were accurate and reliable greatly aided the acceptance of this now-widespread mapping technology.

I encourage everyone who can make the time to attend the SPE ATCE in Houston at the end of this month. We will have some exciting developments to showcase at our booth (#747) as well as many new case studies and technical overviews to share. I will also present a paper comparing two approaches to horizontal well completion and stimulation in the Barnett Shale. Please come judge for yourself whether I am crazy or not. I look forward to seeing many of you in Houston.

Best Regards,

Chris Wright

Chris Wright
President of Pinnacle Technologies

CASE STUDY: WHICH DO YOU WANT? CONVENTIONAL FRACS? WATER FRACS? BOTH!

Going Hybrid in the Bossier

With much of our industry focusing on waterfracs, Anadarko Petroleum Corporation (APC), an early pioneer of these fracture treatments, decided it was time to move on in the Bossier sand. With its relatively low average permeability of about 0.1 mD, the Bossier first appeared to be a reasonable candidate for waterfracs, as they provided better production response at a lower cost compared to conventional fracture treatments. A closer look at fracture treatment and production performance, assisted by Pinnacle Technologies and our FracSeis direct fracture diagnostic technique along with the development of a calibrated fracture model using the FracproPT system, showed that using a "hybrid" strategy consisting of partial waterfrac and partial conventional treatment characteristics yielded the best results.

This mapping project was performed in the East Texas Basin and targeted intervals within the Bossier sand in newly drilled wells. The Bossier interval, which lies immediately beneath the Cotton Valley Sandstones, is a thick, lithologically complex system containing black to gray-black shales interbedded with fine-grained to very fine-grained argillaceous sandstones.

In the mid-1990s, Anadarko started development of the Bossier using conventional propped fracture treatments, with details of the fracture treatment size and production results provided in the table below.
In the late 1990s, APC started experimenting with waterfracs, following success with waterfracs in the overlying Cotton Valley formation (see SPE 38611). Initial production for wells improved with waterfracs, and this was believed to be due to a dramatic reduction in gel damage and also due to the fact that fractures would be more confined to the target pay, as net fracturing pressures are typically lower during waterfracs. Proppant concentrations in these waterfracs were then gradually stepped up. As proppant loading slowly increased, so did initial production response. This indicated that conductivity and effective fracture length were very important in the Bossier, and that neither

PARAMETER	CONVENTIONAL	WATERFRACS	HYBRID FRACS
Conducted During	Mid 1990s	Late 1990s	Since 2000
Fluid Type	40-50# HPG	Slickwater	Slickwater pad/30# Borate during prop
Proppant Type	20/40 sand	20/40 sand	40/70 RC ceramic
Avg. Fluid Vol.(bbl)	5,000	10,000	8,000
Avg. Proppant Vol.(klbs)	200,000	20,000-200,000	200,000
Geometry	Out-of-zone growth	Confined; Smaller effective length due to poor transport	Confined; Improved effective length
Conductivity	Poor due to gel damage	Improved with less damage	Improved with less damage
First Month Prod. Rate per Net Pay (MMscf/ft)	20	25-40	45
Avg. Treatment Cost	**$200-350k**	**$50-150k**	**$175-225k**

Figure 1. Fracture Treatment Parameters for conventional, waterfrac and hybrid fracs.

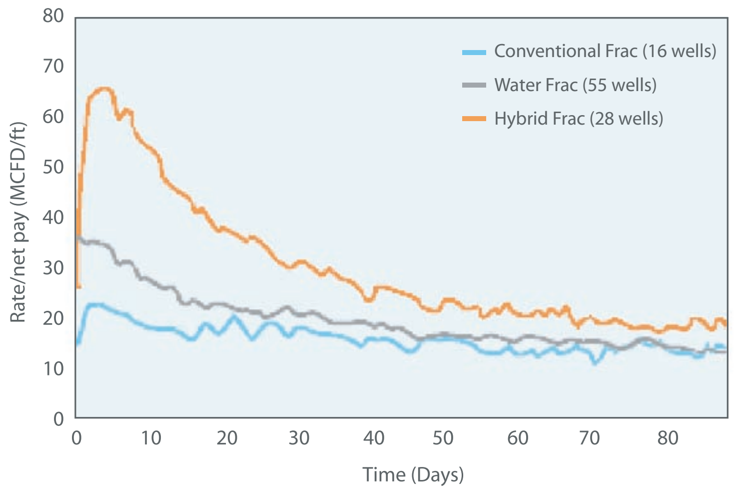

Figure 2. Initial production response averages for three different types of fracture treatments pumped in the Bossier.

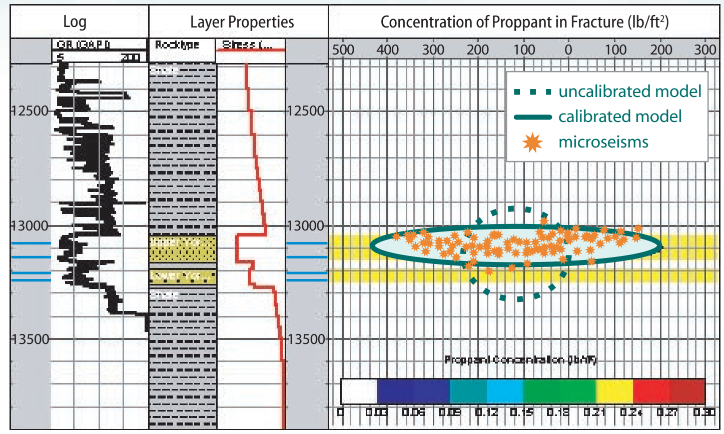

Figure 3. Fracture geometry for calibrated and uncalibrated model compared with FracSeis mapping data.

of these parameters had been optimized in the way that they had for Cotton Valley water fracs. Therefore, APC saw more room for improving propped fracture length and proppant conductivity. This was achieved by using a fracturing fluid with damage characteristics close to slickwater and the transport capabilities of a gel—thus the "hybrid" fracture treatment was born, using a slickwater pad and a low-loading gel for slurry. At the same time, conductivity was enhanced by switching to ceramic proppant.

To summarize, the objectives of the "hybrid fracture" design were to:

- Create the contained fracture height growth observed in Bossier waterfracs;
- Obtain proppant transport similar to conventional crosslink gels;
- Improve treatment success by reducing screen-outs;
- Decreasing gel damage compared to conventional crosslinked gel treatments;
- Lower gel and fluid cost compared to conventional crosslinked gel treatments;
- Increase effective fracture half-length

Figure 2 illustrates the sequential improvements seen in frac strategy.

Pinnacle Technologies' microseismic mapping services were utilized to investigate the merits of this new hybrid strategy. Figure 3 shows the difference between an uncalibrated and a calibrated FracproPT model run for the Bossier. As shown by the microseismic events, a higher shale content in the lower York is enough to prevent fracture growth through the full York interval. The uncalibrated model run does not appropriatrely capture the observed fracture growth behavior. The calibrated model, which relies on some level of composite layering for height growth through laminated layers, does capture the actual growth behavior quite well, while also matching the observed net pressure response during the treatment.

APC uses FracproXACT, the FracproPT Design System that incorporates formation and area dependent model settings, as a reliable and predictive tool to design future fracture treatments in the Bossier.

Additional information is available in SPE 84488, 84489 and SPE 89876 (which will be presented at the 2004 SPE ATCE).

TECH UPDATE: UNCERTAINTY ANALYSIS OF HYDRAULIC FRACTURE PARAMETERS MEASURED BY TILTMETER MAPPING

(PART 1 OF 2)

As the old saying goes, everything in life is uncertain except death and taxes. This is true of all measurements including weight, volume, diameter, time, distance and tiltmapping. In the past five years, Pinnacle has expanded the operating range of surface tiltmeters from less than 5000' to more than 15,000'. One may ask the question; "How accurate are these measurements?"

Major sources of error. Analysis of hydraulic fracture characteristics from tiltmeter data is subject to two major sources of error: measurement error and model error.

Measurement error includes all of the factors that could contribute to errors in the measurement of tilt induced by the fracture treatment. Sources of measurement error include tool calibration errors, tool position and tool orientation errors. However, by far the largest contributor to measurement error is the unwanted measurement of surface deformation due to sources other than the hydraulic fracture treatment. Some of these sources include thermal motions, nearby water tanks that change level during the treatment, vehicles driving past the instruments and earth tides (Figure 4).

Modeling error includes all of the factors and assumptions that can make the calculated theoretical tilt at each tiltmeter site different from the actual tilt. Sources of modeling error include heterogeneity in the rock between the fracture and the tools, a non-planar free surface and complexity in the fracture shape. The first two sources of error could be significant in very extreme cases, but the third is likely the largest source of error for nearly all treatments where modeling error is larger than measurement error. Generally, this is the case during mapping of treatments using downhole tiltmeters in an offset or treatment well.

Which source is most important?

Surface Tiltmapping. As a rule, surface tiltmeters are located far away (meaning many times the longest fracture dimension) from the fracture. Thanks to this distance, the errors introduced by incomplete modeling of the details of the fracture are insignificant. From far

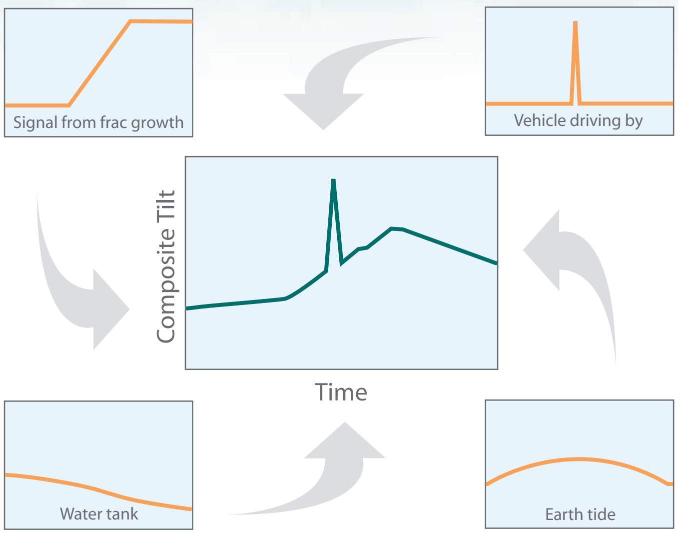

Figure 4. A measured tilt signal is the sum of the signals from the fracture and those from other events.

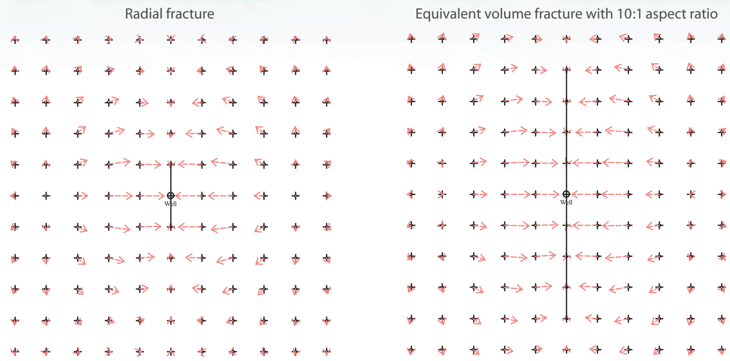

Figure 5. Surface tilt patterns around 2 different vertical fractures. Both fractures have the same volume, but different dimensions. The similarity between the patterns shows that surface tilt mapping is generally insensitive to individual fracture dimensions unless the fracture depth becomes comparable to the fracture dimensions.

away, the fracture appears as an oriented dipole; the tilt field is highly sensitive to the fracture azimuth, dip, volume, and depth, but not to individual fracture dimensions (Figure 5). Since the individual dimensions cannot be resolved anyway, the details of how those dimensions are modeled make little difference in the analysis. Also, since the tools are far away from the fracture and generally close to the earth surface, the measured signals are small and disturbances from surface sources (water tanks, trains, thermal motions, etc) and earth tides may be as large or even larger than the signal from the fracture treatment. For these treatments, the effects of measurement error are much more important than the effects of modeling error. Considering the sources of measurement error, even large errors are normally localized to very few sites so the contour's fit across a large array is largely unaffected.

Quantifying Measurement Uncertainty—Monte Carlo Analysis. The Monte Carlo method of uncertainty analysis is designed to answer the question "Given uncertain measurements, what set of fracture solutions covers the range of possible earth deformation patterns?" The question is answered by assuming the measured tilt is incorrect by some amount, changing each tilt measurement in a random direction then finding a new solution to fit the revised measurement.

The following procedure calculates the uncertainty in the fracture parameters:

1 The noise level in the data is evaluated by measuring how much signal would be extracted during a time when no signal should be present. Most commonly, data is used from a period 24 hours before the actual fracture treatment to determine average noise levels.

2 The measured tilt at each site is modified by a noise vector. The noise vectors have random orientations and magnitudes that follow a Gaussian distribution with the same average as the measured value from Step 1.

3 An inversion routine finds the fracture parameters that best fit the modified tilt data. The frac parameters produced by the analysis are stored in a database.

4 Steps 2 and 3 are repeated 100 times with a different set of noise vectors each time.

5 The uncertainty is reported as the standard deviation of the fracture parameters in the database.

This method accounts for randomly distributed errors in tool calibration, tool position, tool orientation and perturbations unrelated to the fracture treatment. It does not account for systematic errors in tool calibration, tool position, and tool orientation, but these errors are easily made negligible by careful field operations and a program of checking data. For instance, tool calibrations can be verified in the field to a reasonable degree of accuracy by mapping the earth tides, which have a known magnitude. *See our next issue for the conclusion of Tilt Uncertainty Analysis for discussions of downhole tiltmapping and error quantification for surface and downhole tiltmeters.*

NEW MEMBERS OF THE TEAM

Harold Merry has joined Pinnacle as Director of Business Development for Reservoir Diagnostics. Harold has more than 24 years of industry experience with Schlumberger, Input/Output and most recently Oyo Geospace. Robert Kramm is a Project Manager in Houston and comes to Pinnacle with a wide range of domestic and international engineering experience with Arco and BHP. Heath Nevels is a new member of the Engineering Services group and Dave Quirk is aboard as our newest Project Manager in Calgary, both come to Pinnacle from BJ Services. Shane Quimby is aboard as FracSeis analyst in Houston, coming to us from CoreLab's RTD division. Dr. Ulrich Zimmer is our newest FracSeis analyst in Houston, coming to us from Advanced Geotechnology Inc. Mike Rightmire has opened Pinnacle's new Dallas office and is a Sr. Reservoir Engineer with 20 years of experience with Arco and as a consultant. Catch one of these rising stars on your next project!

COME SEE PINNACLE AT SPE

Fly on by to booth #747 and see Pinnacle's "Jumbo Jet" offerings at this year's SPE ATCE in Houston, September 27–29. Visit old friends, make new ones and come hear presentations of our new papers!

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NEWSLETTER

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FracproXACT

FracproXACT puts the power of FracproPT into your hands for significantly less cost than our real-time version. Specifically intended for the design of fracture treatments, FracproXACT is used pre-frac to determine the optimal treatment volume and parameters. Combined with our XACT calibrated model settings derived from fracture mapping of thousands of treatments in many reservoirs, FracproXACT provides the most accurate fracture geometry prediction available today.

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