SPE 29443

A Case History of Completing and Fracture Stimulating a Horizontal Well

Hazim H. Abass,** Peter Hagist,* James Harry,† James L. Hunt,** Mark Shumway,† Naz Gazi**
*Pennzoil, **Halliburton Energy Services, †Choctaw II Oil and Gas, Ltd.

SPE Members

This paper was prepared for presentation at the 1995 SPE Production Operations Symposium, Oklahoma City, April 2-4.

Abstract

This paper presents a detailed description of the completion and fracture stimulation of a high-angle well in the Madison formation of the Williston Basin in North Dakota. The case history of the Candee 26-13 HA well is used. The completion and fracture stimulation techniques used on this well resulted in a three and a half-fold increase in the ultimate recovery of the well, in comparison to a vertical well in the same field.

The well was directionally drilled to intersect natural fractures and provide optimal conditions for hydraulic fracture stimulation. To ensure zone selectivity and isolation, the well was cased and cemented. Notching techniques were used to allow hydraulic fracture treatments to be selectively initiated along the wellbore. Matrix acidizing was an essential phase to achieve this goal.

This paper also presents a discussion of how reservoir simulators can be used to optimize the number of fractures needed to cover a given drainage area. In addition, prefracture and postfracture evaluations are discussed.

References at the end of the paper

Introduction

The primary benefit of drilling a horizontal well is to take advantage of a greater effective drainage area than that available from a vertical well drilled in the same area. Fracturing a horizontal well has presented problems because of premature screenouts and high treatment pressures. In most geological formations, the orientation angle of a horizontal well from the maximum horizontal stress plays a crucial role in achieving a successful stimulation treatment. The following three mechanisms related to wellbore orientation relative to the maximum horizontal stress (orientation angle) need to be addressed.[1]

- *Fracture-wellbore communication area.* Two extreme cases, longitudinal and orthogonal fractures, provide maximum (longitudinal) and minimum (orthogonal) communication area between the wellbore and propagating fractures.
- *Fracture geometry near the wellbore.* Fracture geometry is an important factor that may cause early screenouts. Several different fracture geometries can result when a horizontal well is fractured, including multiple fractures, T-shaped fractures, and complex fractures.

- *Fracture tortuosity near the wellbore.* This phenomenon occurs when the wellbore is oriented in such a way that the fracture must go through a reorientation process. This process results in fracture surface roughness, which restricts flow and can cause premature screenout.

Soliman et al.[2] discussed the situation in which multiple fractures are created from a horizontal wellbore. They used an analytical model to show the effect of fracture conductivity near the wellbore on production performance. The optimum number of fractures along the horizontal wellbore for a given drainage area was also discussed.

Austin et al.[3] emphasized the importance of casing and cementing the horizontal section to allow for fracture-initiation points to place multiple fractures along the horizontal well. Overbey et al.[4], presented a case history on using external casing packers to divide the horizontal section into several zones for fracture stimulation. The objective of their work was to propagate natural fractures and induce additional fractures at each interval.

Owens et al.[5] presented an application of the tip screenout technique in fracturing horizontal wells. The information presented in this paper is based on more than 100 propped fracture treatments placed from horizontal wells.

The main issues discussed in Reference 5 are (1) the importance of casing and cementing for isolation and (2) performing a good cement job at the interval of fracture initiation to help prevent multiple fractures. Stoltz[6] presented case studies of two horizontal wells used for enhanced oil-recovery purposes.

Background

The objective of the Candee 26-34HA project was to determine if a single, high-angle well drilled through the Ratcliffe and Mission Canyon formations of the Williston Basin could recover reserves equal to the reserves recovered from two to three vertical wells completed through the same interval. The test well was spudded on Dec. 27, 1990, and drilled to a total depth of 9,330 ft on Feb. 6, 1991. Total measured depth was 12,115 ft with a lateral offset of 3,300 ft. A 5 1/2-in. casing was cemented to TD. The well is located on a northwest-southeast trending anticlinal feature in a position where significant fracture enhancement occurs because of structural flexure. The wellbore was drilled parallel to the least principal stresses in an east-west direction across the northern nose of the structure. The principal stress directions were determined from structural analysis and regional fracture directions (**Fig. 1**). The pay zone consisted of approximately 125 ft of primarily fractured carbonate with 4 to 6 ft of 10% porous limestone in the Ratcliffe formation. **Fig. 2** shows a schematic of the wellbore.

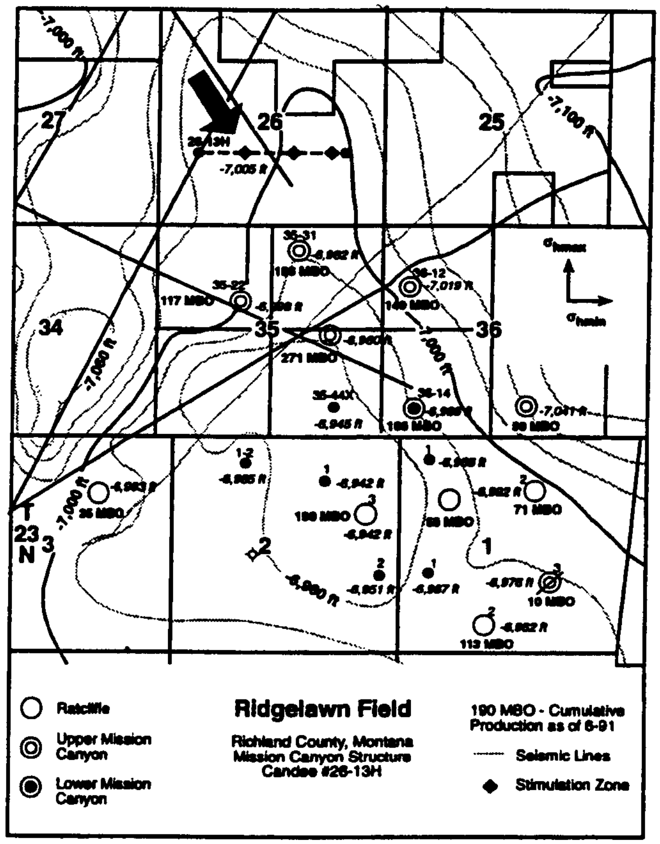

Fig. 1—The principal stress directions determined from structural analysis and regional fracture directions.

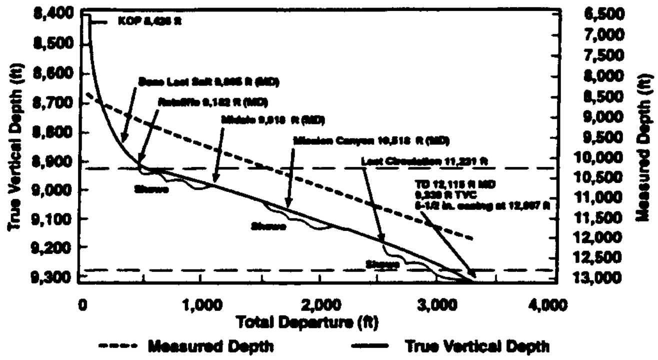

Fig. 2—Wellbore schematic.

Reservoir Considerations

Generally, hydraulic fracturing of a horizontal well is indicated under certain conditions. These conditions include restricted vertical flow, such as those caused by low vertical permeability or impenetrable shale streaks within the productive interval, attempting to intercept swarms of natural fractures with random orientation, and zones with low productivity and/or low permeability.

Once the need for fracturing is established, the orientation of the fractures with respect to the horizontal wellbore must be addressed. Ideally, this decision should be made before the horizontal section is drilled, since the induced fracture direction depends on the orientation of the principal stresses. Fracture orientation can be classified as either longitudinal (where the fracture axis coincides with the wellbore axis) or transverse (where the fracture axis is perpendicular or generally at some angle to the wellbore). Fracture orientation is usually based on reservoir and fracture performance considerations.

The main criterion for transverse vs. longitudinal fractures is the dimensionless fracture conductivity, C_{Fd}, as defined by the following equation:

$$C_{Fd} = \frac{k_f b}{k L_f} \qquad (1)$$

Physically, the C_{Fd} compares the flow capacity within the fracture to the flow capacity of the formation along the fracture length. High C_{Fd}s indicate excess flow capacity within the fracture, meaning that the fracture's capability to deliver reservoir fluid to the wellbore is high relative to the formation's capability to deliver reservoir fluid to the fracture. This behavior suggests little flow restriction within the fracture. Low C_{Fd}s indicate the opposite: the formation's capability to deliver reservoir fluid to the fracture is high relative to the fracture's ability to deliver that fluid to the wellbore. This behavior implies flow restriction within the fracture. When transverse vs. longitudinal fractures are considered, it has been reported that longitudinal fractures are advantageous when the C_{Fd} is less than 5 to 10. Transverse fractures are advantageous when the C_{Fd} is greater than 5 to 10.[2,8]

An additional reason for selecting transverse fractures is that a horizontal well containing multiple transverse fractures has the potential of contacting more reservoir area than a horizontal well containing longitudinal fractures. The additional "reach" associated with transverse fractures allows accelerated recovery of the reservoir, especially in the area between the fractures at early times. Low-permeability reservoirs will benefit from this completion option.

Certain characteristics of transverse fractures should be carefully considered to help ensure effective fracture completion of a horizontal well.[2,8] Because of the geometry of a transverse fracture's relationship with a horizontal wellbore, the fracture's contact with the wellbore is limited as shown in **Fig. 3, Page 4**. Soliman et al.[2] presented an early-time-transient analytical model for a finite conductivity transverse fracture that describes a linear-radial flow regime. Fluid flows from the reservoir linearly into the fracture. Once the fluid is inside the fracture, it flows radially toward the wellbore. The radial flow causes an additional pressure drop within the fracture at the wellbore called *convergence skin*. Economides et al.[8] presented the following equation for convergence skin factor:

$$(S_{ch})_c = \frac{kh}{k_f b}\left[ln\frac{h}{2r_w} - \frac{\pi}{2}\right] \qquad (2)$$

To overcome the convergence skin effect, high C_{Fd} is necessary. Soliman et al.[2] showed that a high C_{Fd} tail-in significantly reduces the radial convergence skin effect. In gas wells, non-Darcy flow contributes to the convergence skin. After a fracturing treatment, high C_{Fd} is necessary for effective cleanup. The presence of high water saturation in the fracture reduces the fracture conductivity near the wellbore, resulting in an effect similar to convergence skin. Generally, transverse fractures need to be designed for higher C_{Fd} values than their vertical well counterparts to overcome the limited contact with the horizontal wellbore.

For the subject well, anticipated C_{Fd}s were well above the 5 to 10 range; therefore, transverse fracture geometry was selected. Evaluation of the convergence skin based on Eq. 2 resulted in a skin factor of 0.013, indicating effectively no radial convergence skin effect within the fracture. This result is not surprising because of the high anticipated C_{Fd} value resulting mainly from the low formation permeability. Preliminary design indicated a fracture half-length of approximately 400 ft and fracture conductivity of about 1,500 md-ft, resulting in a C_{Fd} of more than 100. Even though the C_{Fd} is very favorable, it was decided to tail-in with high-conductivity, high-strength proppant to maintain high C_{Fd} in the near-wellbore region over time.

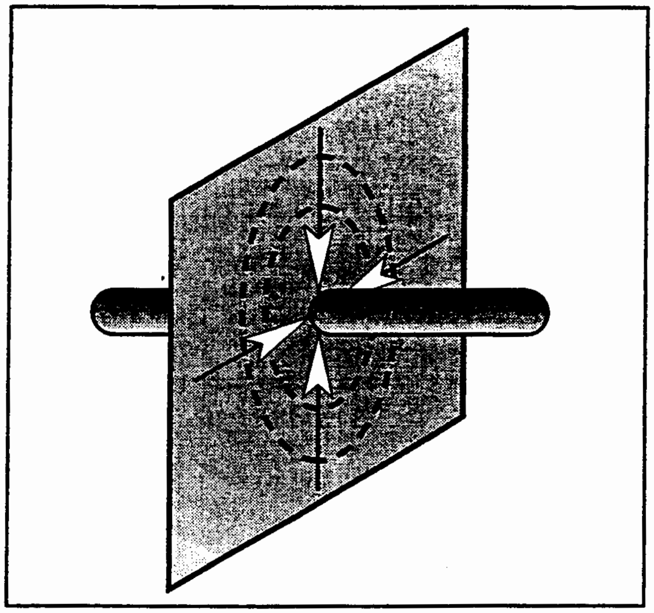

Fig. 3—Fluids radially converge in a transverse fracture approaching a horizontal borehole. This phenomenon causes an unusually high pressure drop in the fluid flow of horizontal wells with transverse fractures.

Rock Mechanics Considerations

When the horizontal section of a wellbore is drilled through the formation parallel to the direction of minimum horizontal stress, σ_{Hmin}, a transverse fracture should be expected during hydraulic fracturing (**Fig. 4**). Transverse fractures initiate and extend at approximately right angles to the wellbore axis. Several different intervals along the horizontal wellbore can be stimulated for optimum reservoir depletion.

A multiple fracture system might be created that could present complex fluid flow problems that hinder a successful stimulation treatment. **Fig. 5** shows the effect of perforated interval length on the number of multiple fractures created. These multiple fractures can

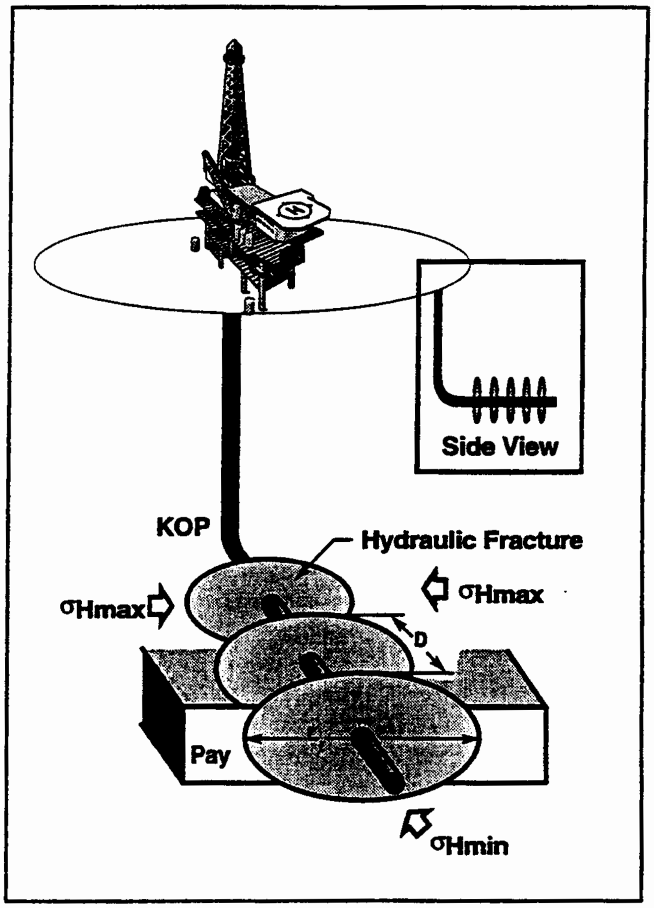

Fig. 4—A horizontal section of a wellbore drilled through the formation parallel to the direction of minimum horizontal stress, σ_{Hmin}.

Fig. 5—Length of the perforation interval affects whether or not multiple fractures are created.

result in reduced fracture width near the wellbore, leading to high treating pressures and/or screenouts.

In practice, it is important to have a clear communication channel between the wellbore and the major fracture propagating under the effect of the unaltered state of stress. Therefore, fracture strands must not be created. To achieve this objective, the following arguments were considered:

- Since the fracture is anticipated to initiate perpendicular to the wellbore (transverse fracture), it is necessary to perforate only a short interval, such as 1 ft.
- To avoid creating T-shaped and/or multiple fractures, it is crucial to ease the near-wellbore stress concentration by creating a large cavity around the wellbore.

The cavity is assumed to dictate the fracture direction and communicate the small fracture width to the wellbore. Creation of the cavity eases the stress concentration around the wellbore, which eliminates the creation of a longitudinal fracture along the wellbore. For example, a wellbore is drilled in the direction of minimum horizontal stress as shown in Fig. 4. The tangential stress at the wellbore and at two locations, in the direction of vertical stress, v, and in the direction of maximum horizontal stress, M, are given as

$$(\sigma_t)_v = 3\sigma_{Hmax} - \sigma_v \quad \text{.................................} (3)$$

$$(\sigma_t)_M = 3\sigma_v - \sigma_{Hmax} \quad \text{.................................} (4)$$

It is obvious that $(s_t)_v$ is less than $(s_t)_M$, which suggests that a tensile failure at the high and low sides of the wellbore will initiate during hydraulic fracturing, creating a longitudinal fracture along the treated interval. This fracture will propagate in the direction perpendicular to the maximum horizontal stress and must go through a reorientation process to become perpendicular to the minimum horizontal stress. Fracture reorientation can result in a rough fracture surface that a proppant may bridge, possibly causing a screenout.

To avoid these problems, an acid job was used to connect all the slots created around the wellbore and form a cavity. Use of this job design achieved two objectives:

- It encouraged the creation of a single fracture from the cavity surface that was oriented perpendicular to the minimum horizontal stress.
- It created a nonrestricted zone between the fracture and the wellbore.

Perforation Design

Perforations play a crucial role in achieving a successful fracturing treatment in horizontal wellbores. The design of the perforating program (phasing, number, size, and perforated interval length) may depend on fracture initiation geometry. Fracture initiation determines the communication path between the wellbore and fracture plane at the wellbore. Nonplanar fracture geometries, such as multiple, reoriented, T-shaped, and other complex fractures (**Fig. 6, Page 6**), are not advantageous; they adversely affect the potential to achieve the required stimulation treatment. The serious problems that can result because of these nonplanar fracture geometries are listed below.

- When two fractures propagate from the same interval, they share the same rock material as they are developing width. Therefore, instead of having a wide fracture, two narrow fractures result. Adequate fracture width is needed to place proppant slurry inside the fracture. If it is too narrow, proppant may bridge near the wellbore

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase®
Smarter legal research.