SPE

Society of Petroleum Engineers

SPE 18263

Simultaneous Multiple Entry Hydraulic Fracture Treatments of Horizontally Drilled Wells

by C.E. Austin and R.E. Rose, Halliburton Services, and F.J. Schuh, Drilling Technology Inc.

SPE Members

This paper was prepared for presentation at the 63rd Annual Technical Conference and Exhibition of the Society of Petroleum Engineers held in Houston, TX, October 2–5, 1988.

II

ABSTRACT

The number of horizontally drilled wells has continued to increase in the past few years. Nearly all of these wells have been completed as "drainholes" with slotted or perforated liner and without a cement sheath. The majority of these have been successful in their designed intent.

Hydraulic fracturing treatments have been performed on a relatively small number of these wells. To be effectively fracture stimulated, a horizontally drilled well must be cased and cemented through the horizontal producing section of the well. Casing and cementing the horizontal section allows fracture initiation points to be controlled in placing multiple fractures.

In situ stresses greatly influence the potential effectiveness of any fracturing treatment procedure. The one factor which most directly affects horizontal wellbore fracturing is the least principal stress, which is at a right angle to the induced fracture. The direction of the horizontal segment of the borehole dictates whether or not the induced fracture will be parallel or at an angle to the borehole.

The use of properly applied controlled entry techniques at several fracture initiation points will help allow equal placement of proppant or reactive fluids in one stimulation treatment. Either fracturing with proppant or fracture acidizing can be used in the stimulation treatment. The potential economic benefit to be derived from a successful multiple entry fracturing treatment merits strong consideration be given to the development of fracturing techniques to help obtain maximum wellbore drainage.

Subject paper explains techniques and methods to be used in creating and placing proppant and/or reactive fluids in each of the multiple fractures in a horizontally drilled well. Economic considerations of the simultaneous stimulation treatment procedure are presented and compared to a vertical well under similar conditions.

INTRODUCTION

Horizontally drilled wells have been around for the last 50 years. Some of the early attempts were experimental efforts conducted in the Soviet Union in the 1950's,[1,2] where some 43 horizontal wells were drilled at considerable effort with respect to equipment, measurement, and theory. The conclusion drawn from this effort appears to have been that horizontally drilled wells were technically feasible, but economically disappointing. In the 1950's, wells were drilled from the shore in the Long Beach California Field to penetrate a productive offshore horizon. Drilling reached a 90 degree deviation angle and subsequently relaxed to vertical to penetrate the producing zone. Because of the production obtained without setting offshore platforms these wells were both profitable and environmentally acceptable. In the 1970's, Mobil, et al. drilled a highly deviated well into the Pine Island Chalk. The well was stimulated by hydraulic fracturing through multiple fracture initiation points. Each of the initiation points was treated separately. As a result of the technology developed for this experiment, Mobil was issued a patent in 1974.[3] Again though, the conclusion based on Mobil's experience appeared to be that horizontal or highly deviated wells were technically feasible but economically disappointing.

gained in the Gulf of Mexico and in the North Sea led to the drilling of more highly deviated wells. The development of "measurement while drilling (MWD)" techniques gave more steerage control for , the directional drilling engineer, giving continuous steering control of the bit. At approximately the same time downhole positive displacement mud motors were being perfected. When used with bent subs these motors further improved the capabilities of the drilling engineer. In fact, at present, drilling technology for horizontal wells is more advanced than the completion techniques.

DRILLING CLASSIFICATIONS

The drilling classification of the highly deviated or horizontal wells being drilled at present falls into four groups:

Group 1. Long Bend Radius (Fig. 1)

- -0 to 5° per 100 ft measured depth
- -Horizontal section in excess of 1000 ft
- -Torque and weight easily applied to bottom of hole
- -Conventional drilling equipment can be used
- -Multiple borehole sizes
- -MWD and continuous wireline measurement can be used for steerage.

Note: If continuous wireline measurement used, then drill pipe cannot be rotated.

Group 2. Medium Bend Radius (Fig. 2)

- -5 to 20° per 100 ft measured depth
- -Horizontal section in excess of 1000 ft
- -Torque and weight easily applied to bottom of hole
- -Conventional drilling equipment can be used
- -Multiple borehole sizes
- -MWD and continuous wireline measurement can be used for steerage.

Note: If continuous wireline measurement used, then drill pipe cannot be rotated.

Group 3. Short Bend Radius (Fig. 3)

- -Bend completed in less than 40 ft TVD
- -Horizontal section usually less than 600 ft
- -Limited size of borehole
- -No continuous steerage at present
- -Limited bottomhole motors at present
- -Most casing tools and stimulation tools cannot traverse bend

Group 4. Ultra Short Bend Radius

- -Bend completed in less than 2 ft TVD
- -Horizontal section usually less than 200 ft
- -Multi-horizontal section at same level radially
- -Specialized completion tools and techniques developed

Note: This group will not be discussed in this paper.

COMPLETION CLASSIFICATIONS

At the SPE Forum on Horizontal Wells held in Durango, Colorado in 1987, the participants present could account for over 110 horizontal or highly deviated wells. Some estimates place the current number of horizontal wells between 300 and 600 wells. Because a large number of the companies keep all information on a "tight hole basis" a closer determination is not possible. The types of production completions performed on horizontal wells are discussed in paragraphs below.

Open Hole Completion (Fig. 4)

Some formations allow an open hole completion without hole collapse. Tubing can be run to bottom to displace mud and debris by turbulent flow. A reactive fluid such as 15% HCl acid is sometimes spotted over the open hole section, then a matrix-type squeeze is applied in an attempt to correct near-wellbore damage. This type of completion is used in long, medium, and short bend radius drilled wells. Dual straddle inflation packers have been used to assist in the control of matrix acidizing treatments.

Slotted or Perforated Liner or Casing Completion (Fig. 5)

The liner or casing should be equipped with internal wash pipe so that mud and debris can be removed from the annulus. A reactive fluid can be placed in the annulus and a matrix type treatment performed in attempting to remove near wellbore damage. This type of completion can be used on long, medium, and short bend radius drilled wells. Casing straddle packers have been used in an attempt to remove the mud and debris from the annulus with some degree of success.

External Casing Packers with Tubing Operated Ported Subs (Fig. 6)

External casing packers isolate sections of the horizontal part of the well. Tubing operated ported subs are sometimes placed on either side of the external casing packers. This type of completion gives the operator a large measure of control in removing mud and debris, and for matrix acidizing. This completion is usually limited to long and medium bend radius drilled wells. In one particular well, straddle packers with a 400 ft spacing between the packers were used. The tool was set 12 times in the process of removing mud and debris, performing matrix acidizing, and testing of the various isolated sections in this well.

Cemented Liner (Fig. 7A) or Casing (Fig. 7B)

This is the most favorable type of completion for stimulation by either hydraulic fracturing treatments with proppant or fracture acidizing. The cement and casing allow fracture initiation points to be placed in the casing, thus allowing control of the fracture treatments. This type of completion is used in long and medium bend radius drilled wells

The cemented liner completion is also being used in formations containing a gas cap. The deviated borehole is drilled to the bottom of the producing zone and is then drilled upward at a slight angle to the top of the zone. A liner is cemented and the well completed by perforating for radial flow. If the well is producing an excess of gas a plug can be set in the upper part of the liner with a choke to control gas flow, thereby assisting the lifting of the crude to surface.

Pre-Packed Liners (Fig. 8)

This type of completion has been used in the North Sea in a field where the producing zone is poorly consolidated. This completion is used on long and medium bend radius drilled wells. A wash string is placed internal to the pre-packed liner to remove mud and debris from the annulus. The hole is allowed to collapse onto the liner and all production is through the pre-packed gravel liner.

Screen with External Gravel Packing

At present there are no reports of horizontal wells having been completed by gravel packing. Several service companies believe that the gravel packing completion can be easily performed; however, this type of completion is limited to long and medium bend radius drilled wells. Sand production has not been reported to be a problem in two cases in which gravel packing might have been anticipated: one in Alaska with cemented perforated liner, producing approximately 10,000 bbl/day and one in Canada producing from a tar sand.

FRACTURE STIMULATION TREATMENTS

This paper is intended to discuss primarily the fracture stimulation treatments of horizontal wells. Most of the completions to date of horizontal wells have been completed as "drain holes." These horizontal wells are being drilled into producing zones that are known good producers in vertical wells. Some believe that a producing zone that requires fracture stimulation in a vertical well will also require fracture stimulation in the horizontal well. Also, some of the tighter zones that are harder to produce and are economically questionable at present may be economically feasible using hydraulically fractured, horizontal completions. Theoretically, by using multiple fractures in the horizontal well, the same amount of total production will be recovered at an accelerated rate, thus the economical payout of the well will be obtained in a shorter time period.

Producing Zone Data Acquisition

For optimum results in fracture stimulation of a horizontal well, some information should be obtained to help in drilling the well and designing the stimulation treatments. Initially, a pre-drilling survey should be made. In this survey information obtained should include (1) tops and bottoms of the producing formation in other wells in the field, (2) induced fracture azimuth, (3) cumulative and daily production of the wells in the field, (4) if drill stem testing has been performed, offsets, and (6) any other information available that may be beneficial to a successful completion.

The lease area should be large enough to allow the drilling of the desired length of horizontal section. If the induced fracture azimuth is deemed accurate, then the well can be planned for an area of the lease. When geological conditions allow, it is preferred that the horizontal section be at right angles to the induced fracture azimuth.

Plans should be made in the drilling prospectus for vertical hole data acquisition. This data can be obtained by drilling the vertical hole through the planned producing zone or by making the first 45° of the bend radius and by using a tangent section (Fig. 9). Extending the tangent section through the producing zone will allow important data to be obtained, including the depths of the top and bottom of the producing zone. While drilling, individual microfrac treatments should be performed on the zones above and below the producing zone in addition to the target zone itself. An oriented core should be obtained from the zones above, below, and within the producing zone. If the hole is vertical, then the fracture direction may be determined directly from an oriented core which was fractured during the microfrac treatment. This has been done in about 70% of the microfrac tests performed in vertical sections.[4] If the tangent section is used then the same data can be acquired. Coring should be oriented and strain relaxation[5] also can be performed to obtain the induced fracture azimuth. A series of wireline open hole logs can then be obtained. One of the logs should be the rock stress presentation of the long space sonic log. This information, when calibrated by data obtained from microfrac tests, should give sufficient least principal stress data to determine the vertical placement of the horizontal section. This information may be input into a 3D computer model to predict the geometry of the induced fractures. The depth of the top and bottom of the producing zone and the vertical position of the horizontal section will be used by the directional drilling engineer to complete the bend radius and to steer the borehole into the desired position.

If data acquisition is performed in the vertical hole, this hole will be plugged back to the kick-off point. If the data was acquired in the tangent hole, then the plug back depth will be the kick-off of the second 45° segment of the bend (Fig. 9). A planned tangent section between the first and second 45° section of the bend allows for corrections in entering the correct vertical placement of the horizontal section.

Horizontal Section Drilling and Cementing

Most horizontal wells can be drilled and completed with the same sizes of casing set at the same vertical depths as the conventional wells in the area. If an intermediate protection casing is require, the horizontal well can be completed with a liner. If no intermediate cased and cemented with a casing string run from the surface.

The horizontal section can then be completed as planned. The mud system should be carefully controlled and monitored to prevent excess solids accumulation and to assist in the removal of cuttings from the horizontal section. After reaching the desired TD, the casing or liner should be run and cemented. Recommended cementing practices by Keller et al.[6] and Wilson et al.[7] include a non-settling, 0% free water cement. If completed with a liner, the liner top should be placed in the straight tangent section of the bend radius and tied into an intermediate casing. This practice should assist the entry of tools into the liner with a minimum of trouble.

PLANNING STIMULATION TREATMENTS

While the horizontal section of the well is being drilled, cased and cemented, some decisions can be made. Using the data obtained from the producing zone, the following should be determined or established: (1) maximum treating rates (2) fracture initiation points,(3) fracture design(4) perforation design, and (5) pre-frac considerations.

Maximum Treating Rates

The size of the long string or the intermediate casing and liner will determine the maximum rate that can be pumped down the casing without causing damage. If the velocity of the fluid in the tubular goods is greater than 100 ft/sec then severe erosional damage can occur at the joints and offsets of the tubulars; when the fluid contains proppant the damage is magnified. Erosional damage is minimized if velocity is limited to 80 ft/sec. The maximum recommended rates for different size and weights of tubulars are shown in Table 1. The rate can be limited by the equipment used to perform the stimulation treatment with proppant. For example, the blender becomes a controlling factor when describing the maximum rate in terms of pounds of proppant per gallon. This rate is between 50 to 60 bbl/min at 6 lb/gal of proppant. Thus, it can be seen that if the required stimulation rate is approximately 110 bbl/min, then two blenders will be needed. In designing the total stimulation rates, the service company performing the treatment should be contacted to assist and advise the rate, proppant concentration, and equipment for designing the stimulation treatment, based on equipment specifications.

Fracture Initiation Points

The number of initiation points can be arbitrarily selected or can be determined by a computer model. Figures 10 and 11 show the output from a single phase, finite difference fractured well simulator.[8] No fluid is assumed to cross the lease boundary and fractures are uniformly spaced along the horizontal wellbore. Fracture flow capacity for each fracture is obtained from fracture simulators that are to be used in the stimulation design. Figures 10 and 11 indicate that for this specific example five to seven fractures will be the most effective number in draining the lease. This

In the absence of computer models or better guidelines the initiation points are generally spaced 250 to 300 ft apart.

Fracture Design

Parameters of the treatment depend on data acquired from (1) the production zone, (2) the zone directly above, and (3) the zone directly below, during the data acquisition phase discussed in previous paragraphs. Also, the rock stress presentation from the long-spaced sonic log is calculated for each zone, then this and data acquired from the zones are used to calculate an average least minimum stress for the three zones. A fully 3D fracture design simulator can then be used to determine the fracture geometry, (height, length, and width) for a given treatment, and a 3D simulator can be used to create data similar to that shown in Figs. 12-15. Figure 16 shows an example cross section of the zones with their calculated minimum stresses; geometry of the fractures is controlled by these stresses. If a water producing zone is near the hydrocarbon producing interval, then the fracture should be designed so that it will not extend into the water producing zone. After fracture geometry is determined by the simulator, additional calculations are made for proppant transport and placement. Figure 17 shows this output.

Perforation Design

When the number of initiation points, the geometry, and the treatment rate for each fracture have been determined, the number and diameter of perforations in each initiation point must be designed. To calculate the parameters for the perforations, a process called the Limited Entry Technique[9,10] is used. The formula for this calculation is shown in Eq. 1 and the formula for the perforation coefficient is shown in Eq. 2. The perforation coefficient varies during the stimulation treatment. The perforations have a sharp edge which causes the fluid flow profile to decrease in diameter as it flows through the perforation (Fig. 18). Within minutes after proppant has been pumped through the perforation the sharp edge is lost and a rounded edge appears (Fig. 19).

Crump[11] et al. showed that the perforation coefficient (C_p) with a sharp edge is approximately 0.5 and after proppant flows through the perforation the erosion rounds out the perforation and the perforation coefficient approaches 1.0. Crump also showed that the diameter of the perforation increases only slightly; the major change is the increase in the perforation coefficient. Table 2 shows a table of calculations using the Limited Entry Technique to determine the number of perforations. Based on a rate of 13 bbl/min and a perforating charge of 32 grams in 5.5 in., 23 lb/ft casing, the nominal perforation diameter should be 0.54 in. Assuming the operator wanted the perforations horizontal in the pipe the design diameter is 0.55 in. (The gun is slightly below the center of the casing.) Also, if the gun is laying distance from the casing the minimum diameter is 0.51 in. Table 2 was calculated using linear gel fluid with coefficients of 0.5 and of 0.95. Also shown is the perforation friction for the different sand concentrations for the proposed sand schedule. A minimum perforation friction of at least 250 psi is required. The use of four holes for this size gun meets the design requirements. Note that before proppant erosion the perforation friction ranges between 797 to 1,243 psi, and after erosion the range is from 221 to 462 psi. These calculations are similar to the calculations used in a previous fracture stimulation treatment in which nine fractures were stimulated simultaneously.

$$P_{pf} = 0.237\,FD \frac{(R^2)}{(N^2 \; C_p^{\,2} \; D_p^{\,4})} \qquad (1)$$

$$C_p = \frac{D\nu}{D_p} \qquad (2)$$

Pre-frac Considerations

Before the actual treatment is pumped, each set of perforations at each initiation point should be broken down and an injection rate established. To perform this operation, a straddle packer is used. The packer is so designed as to provide a minimal amount of friction pressure after the fluid leaves the tubing and before it enters the perforations. This operation is essential for the simultaneous multiple entry hydraulic fracture treatment. Also, the breakdown with a straddle packer creates and initiates an individual induced fracture. This operation should ensure that all initiation points take equal volumes of fluid and proppant. During the breakdown operation, pre-fracture measurements may be obtained and the designed stimulation treatments modified, if so warranted, from the information acquired from the following pre-fracture techniques: (1) Shelley,[12] (2) minifrac,[13,14] or (3) a combination of these.[15]

A well with 2,000 ft of horizontal section was fracture stimulated with proppant using the procedures presented in this paper. Surface indications (designed rate and treating pressure) were positive that all nine initiation points were fractured and propped simultaneously at a total rate of 108 bbl/min with a delayed crosslinked gel carrying a maximum proppant concentration of 6 lb/gal. Each initiation point was treated at a rate of 12 bbl/min. A radioactive tracer was used in the proppant, and the log performed after the treatment indicated that all initiation points contained radioactive proppant.

Cost Effectiveness

The cost of drilling a horizontal well with a 2000 ft horizontal section has been reported as twice that of a vertical well. The cost may actually run several times higher on a company's first attempt at a horizontal completion. As experience is gained, however, the cost of drilling/completing subsequent horizontal wells should drop. The horizontal wells drilled on the North Slope are reported to be costing 1.25 to 1.5 were drilled. The first well had a cost factor of approximately seven. The same should be expected in drilling horizontal wells for fracture stimulation. The early wells will be more expensive than later wells when experience will reduce the cost. It is expected that the cost for a fracture stimulated well can be less than twice that of a vertical well.

If stimulation treatments are performed one at a time in horizontal well completions, the cost is the same as if each treatment was similar to a vertical well. One way to reduce cost is to perform all the treatments by using the simultaneous multiple entry fracture techniques. For example, one well has had nine fractures created and treated at one time. Other wells have been planned that will have three sets of three fractures performed simultaneously. Whenever multiple simultaneous fracture treatments are performed the total cost of stimulating will be less compared to performing multiple individual treatments.

Fracture Acidizing vs Fracturing With Proppant

This paper has mainly referred to fracture stimulation treatment with proppant. This type of fracturing is performed more than fracture acidizing since fracture acidizing can only be performed on carbonate producing zones, and not all carbonates are effectively stimulated by fracture acidizing. However, where fracture acidizing can be used effectively because of the higher fracture conductivity, the results are usually better than obtained by fracturing with proppant. If a producing zone can be stimulated by fracture acidizing the same basic steps given in this paper can be used to perform the treatments by using the simultaneous multiple entry hydraulic fracture technique using a reactive fluid, i.e., acid.

SUMMARY AND OBSERVATIONS

Simultaneous multiple entry hydraulic fracture treatments are presented as a viable and economical method for hydraulic fracture stimulation of horizontal and highly deviated wells.

Many methods of horizontal completion used are usually dictated by the reservoir.

Comprehensive reservoir data is a necessity for designing simultaneous multiple entry hydraulic fracture treatments.

The following observations are supported by present horizontal well drilling and completion trends:

1. The number of horizontal wells drilled will increase as more successes are achieved and more information is made available to the industry.

2. The number of completions with slotted liners will decrease and other types of completions affording more control for the

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.