Open-hole completion system enables multi-stage fracturing and stimulation along horizontal wellbores

By Rocky Seale, PackersPlus

DRILLING DEEPER AND horizontally has become more viable in many reservoirs. Successfully completing these deeper gas reservoirs and horizontal wells, however, is still a challenge the industry faces on a daily basis. As drilling technology continues to exploit these more complex and unconventional reservoirs, completion technology is being designed and developed to effectively fracture and stimulate multiple stages along a horizontal wellbore.

The growth in multi-stage fracturing has been tremendous over the last four years due to completion technology that can effectively place fractures in specific places in the wellbore. By placing the fracture in specific places in the horizontal wellbore, there is a greater ability to increase the cumulative production in a shorter time frame.

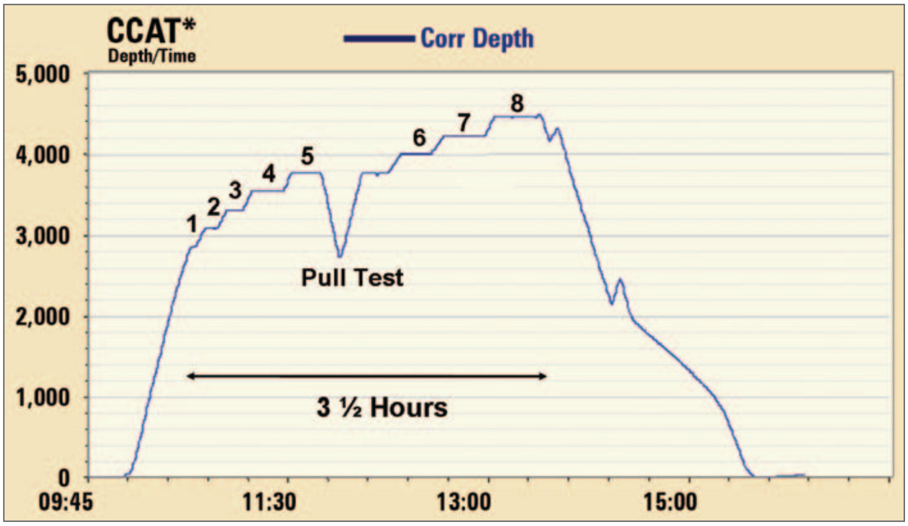


Figure 1 (above) illustrates the drillability of the FracPort seats, showing that eight seats were drilled out in 3.5 hours. Figure 2 (below): A variation of the StackFRAC system allows the intermediate casing string to be eliminated.

This article details an open-hole completion system run as part of the production liner that does not require cementing and provides mechanical diversion at specified intervals, thus allowing fracturing operations to be effectively pumped to their targeted zone. It effectively eliminates the need for cementing the production zone to establish mechanical diversion as desired, which can take weeks to complete at high costs and elevated mechanical risks and causing deeper reservoirs to become uneconomic to exploit.

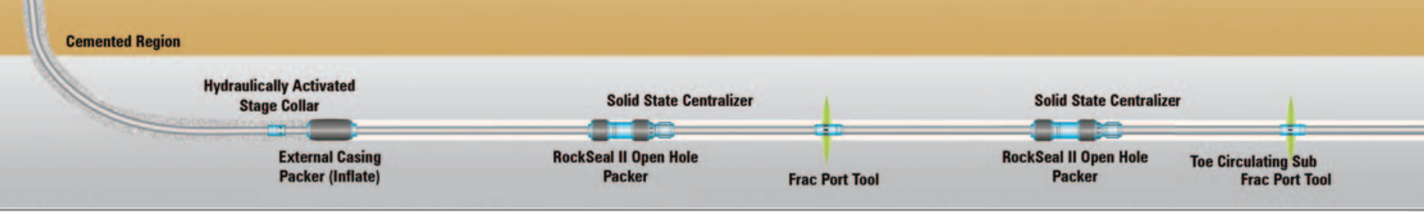
DEVELOPMENT

Horizontal drilling has advanced significantly over the last decade to become the field development method of choice in many cases. However, certain limiting technologies in the completion of horizontal wells have slowed that growth in some reservoir applications. These have been reservoirs that require specific fracturing treatments at certain intervals to make them economic to produce. Vertical stimulation techniques, such as limited entry and bullheading, have proven no more beneficial compared with vertical wells. Post-production analysis on the deliverability of horizontal wells in reservoirs, such as matrix, heterogeneous and non-conventional formations, have shown a direct correlation to the completion and stimulation methods employed and the subsequent shortcomings when applied to horizontal wellbores. Thus, the additional economics required to drill a horizontal well in these applications have not been justified by the equivalent or slightly better production results compared with vertical wells.

Before the development of the StackFRAC system, the only options for completing an open-hole horizontal well was either barefoot or using slotted or perforated liner. These designs were inflexible in fracturing options, and they didn't address the requirement for mechanical diversion as evidenced by microseismic data obtained during horizontal limited-entry treatments conducted in various reservoirs. Thus, beginning in 2000 and continuing over two years, various product components and systems were tested and deployed in the field, leading to the StackFRAC system.

By developing a system to set in open hole, provide mechanical diversion and allow multiple fractures to be performed along the entire horizontal wellbore, problems with open-hole horizontal completions to date were addressed, with the added benefit of cost and time savings due to its efficiency.

The mechanical open-hole packer system is capable of withstanding high differential pressures, with fracturing ports located between the packers. A series of these could be run simultaneously in the well on a liner, and the fractures could be pumped in continuous succession. This eliminates the problems encountered when cementing horizontal liners



in place. It also eliminates the need for repeated CT intervention into the well for setting and removing composite bridge plugs, running perforating guns, and the repeated rigging up and down of the fracturing or stimulation equipment.

By using continuous pumping on all the fractures intervals, the pumping equipment needs to be rigged up and down only once, saving time and money and reducing the associated HSE hazards.

SYSTEM DEVELOPMENTS

After identifying the deficiencies in open-hole horizontal completion and fracturing options, a development was initiated to provide a viable solution with the same attributes of a cemented and perforated completion using composite plugs for mechanical isolation. Based on the North American fracturing market, it was determined the differential pressure rating of the open-hole packers needed to be 10,000 psi at temperatures up to 450°F and set in holes enlarged up to 40%, while conforming to hole irregularities, including ovalities, washouts, etc.

Additionally, it was determined that the mechanical packers must be hydraulically actuated and set. Analysis also found a dual-element system was optimal for the higher pressures the packer would see from each direction. Thus, a patented redundant seal over a specified length was developed. The packer could therefore optimize the mechanical diversion within each designed section length in any open-hole horizontal wellbore while being set hydraulically in tension or compression, be mechanically locked and yet limber enough to navigate higher doglegs encountered in short-radius drilling environments.

Equally critical to the system design was development of the fluid placement method between the packers. The fracturing system had to be designed to selectively open at specific times and, once open, withstand the abrasive fracturing fluids for extended periods of time. Initial layouts for the fracturing port (FracPort) designed for the maximum flow area the system required while retaining the desired tensile and compressive strengths as the standard parent liner for the size in question. For example, in 8 ½-in. open-hole, the standard completion is 7 in. or 5 ½ in., so the mechanical properties of the FracPort were designed to exceed 7-in. 29 ppf and 5 ½ in. 17 ppf P-110 liner properties, respectively. Thus, the flow area of 7-in. 29 ppf liner is 30.04 sq in with a tensile strength of just over 750,000 lbs and burst and collapse pressures around 10,000 psi. The 7-in. FracPort has a 25% larger flow area than the liner, while maintaining the tensile strength of over 750,000 and having a burst and collapse pressure of 10,000 psi. This same design concept holds true for all sizes from 2 ⅜-in. to 7-in. tools for hole sizes ranging from 3 ¾ in. to 12 ¼ in., while every component in the system is rated to 10,000 psi working pressure.

The next design step was to determine the activation process for the FracPort. With operational functionality and efficiency in mind, it was determined that ball activation would be most reliable. This would eliminate CT, slickline, wireline and other wellbore interventions to accomplish the desired number of fracs. After dropping the ball, it could be pumped down in the flushing fluid of the previous fracturing interval and land in a specific seat to activate that FracPort for the next interval and provide a seal on the seat to prevent treating the intervals below.

Development of the ball seats within the FracPort was an engineering challenge. The seats would be exposed to high pump rates with various fluids for fracturing with high sand concentrations. Therefore, the seats had to be designed to withstand the high erosional effects of fracturing proppants. Extensive design and testing went into establishing not only the geometry of the seat but the proprietary material specifications. The balls and seats were then sized within each system to allow the process to be repeated numerous times on a single job. Based on the open-hole diameter and liner size, up to 18 stages can be pumped into a horizontal wellbore at one time.

DRILLABLE FRACPORT

The next step was to apply the erosion resistance technology of the ball seats into a design that could be easily milled. By using a drillable material, all obstructions in the liner could be removed, allowing full access to the toe of the wellbore for standard operations associated with CT, logging, flow testing, etc., to be carried out. A design was developed through investigation of metallurgical properties cross referenced to drillability with carbide mills.

To qualify the various size FracPort seats, prototype equipment was built using the same geometric configurations as had been proven with the Standard FracPort. After function testing, a surface milling test was performed to establish the optimum drilling parameters of the seat in conjunction with a specified mill design. The drillability of the seats has been quantified in the field by drilling out over 500 seats. Through this field data, the drilling parameters and operations have been optimized. An example of the drillability of the seats is displayed in Figure 1. As shown, eight seats were drilled out in 3.5 hours, a perfect example of how most seats are removed when using CT and motor.

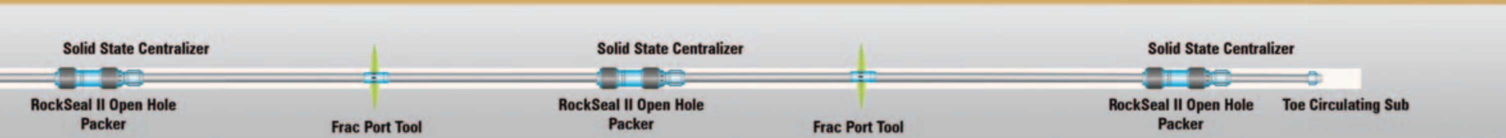
RE-CLOSABLE FRACPORT

A specific FracPort was designed and built in 2003. This design incorporates the same design principles as used in both the Standard and Drillable versions. However, it selectively allows the FracPorts to be closed and re-opened. A major limiting issue associated with current completion designs in certain reservoirs is the inability to close off a horizontal section due to water encroachment or the ability to effectively re-stimulate without introducing smaller tubulars, which in turn increases the friction pressure and reduces the rate at which the frac can be pumped.

The Re-Closable FracPort design allows any number of sections to be closed to inhibit production from that zone, or all stages can be closed, leaving only the last one open, and the well can be re-fractured as it was initially, by dropping balls and pumping specifically designed fracturing treatments for each specific section of the horizontal well.

CASE HISTORIES

In more than 600 installations of the system, more than 3,000 stages have



been fractured, covering more than 1.2 million ft of horizontal open hole. Additionally, more than 200 million lbs of proppant have been pumped through StackFRAC systems in hole sizes from 3 ¾ in. to 12 ¼ in. and in various formations such as sandstone, shale, limestone, dolomite, chalk and coal. The maximum number of stages currently possible is 18. The maximum continuous pump time has been 26 hrs, and the maximum pumping rate through a system has been 145 BPM.

In one eight-stage horizontal well, a record was set with 3.5 million lbs of proppant pumped. These systems are routinely deployed in horizontal wells with open-hole sections of more than 4,000 ft in length, with the maximum horizontal well run in to date being 7,200 ft. Recently, the system was deployed in an extended-reach well where the liner top was set at 17,100 ft MD and 7,100 ft TVD, and the shoe was set at 23,000 ft MD and 7,100 ft TVD. These records have not only proven the system's durability but also provided insight to the ability of successfully running completion hardware in the hole.

The broad scope of applications should also be noted: The systems have been run consistently to depths ranging from 1,000 ft TVD to 18,000 ft TVD, and temperatures up to 380°F, mud weights in excess of 18 ppg as well as in the presence of H_2S and CO_2.

On a comparative analysis, the deployment of the system takes 5% to 7% longer than running a standard liner assembly while providing mechanical isolation and the ability to initiate fractures at desired points along the horizontal wellbore. The time difference in deploying the system, however, is more than made up by not having to cement the liner in the well.

The RockSeal Packers and FracPorts are pre-assembled and tested prior to being sent to location, thus expediting the deployment process and providing the ability to change the spacing of the fractures as required when the well is completed. This allows for optimal spacing between the packers and the deployment of blank sections to isolate sections that do not require fracturing, such as a fault. The functionality is also prevalent in the ability of all the components in the system to navigate high doglegs while maintaining minimal diametrical clearances. As opposed to standard open-hole packers, these packers are shorter and more flexible,

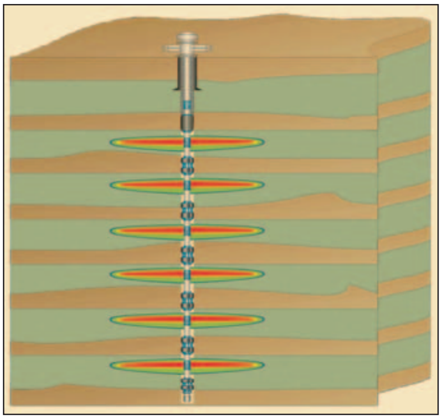


Figure 3: Applying StackFRAC to vertical open hole wellbores allows zones to be isolated without cementing and allows the long string to be cemented in place back to surface for upper ground water isolation. Once installed, the system accommodates multiple zone stimulations in a single operation.

allowing for larger ODs while managing to navigate higher doglegs and then function properly once on depth.

Certain aspects of the system vary compared with conventional operations. Fracture initiation pressure is nearly always less than cemented and perforated applications due to the associated skin, yet higher compared with open-hole bullheading applications. The pressure variation of the system from stage to stage has proven invaluable in determining the effectiveness of the mechanical diversion. What has been witnessed in the field is when the horizontal wellbore is partitioned, each compartment has a unique pressure signature for fracturing. This unique pressure signature for each stage provides real-time evidence that the packers are providing the mechanical diversion for which they are designed. If the fracture was going past the packer, then the pressures would be the same for the adjacent interval. The exception to this is when the packers are run very close to one another in what is referred to as a Focus Frac.

For these applications, the fracture initiation point is dictated by the packer placement rather than where the rock is weakest. There has been microseismic run to verify the fracture treatments are going where intended.

In nearly every field experience, the fractures have been pumped in a single operation, taking less than a day to complete, enabling cost savings of $150,000 and the completion coming on line more than a week earlier.

The stated cost savings do not include the benefit of early production. Further to this, systems are increasingly being deployed in both horizontal and vertical wellbores where the intermediate casing string has been eliminated. This is possible by using a variation of the system that allows the upper portion of the liner to be cemented in place and leave the production interval open hole (Figures 2 and 3). This has not only proven more efficient but has also saved hundreds of thousands of dollars in tubular costs.

Experience in running these systems has alleviated much of the initial concerns about getting to TD, even when many have stated that it cannot be accomplished. As a result, many systems now run the RockSeal Packers with blank pipe between to isolate faults, shales or non-productive zones not requiring stimulation. The number of stages incorporated into each assembly also continues to grow, which coincides with the same trend for all horizontal multi-stage jobs. This, in combination with production trends from horizontal wells, is further evidence that mechanical diversion is proving effective.

CONCLUSIONS

Horizontal drilling has grown rapidly over the last decade, but improvements can still have vast impact on reservoir production and depletion. In 2000, a technology gap was identified for horizontal wells with open-hole completions, where mechanical diversion was needed to effectively fracture sections of the lateral. From these initial system developments, the StackFRAC system was spawned. The RockSeal Packer was developed specifically to withstand the harsh environments encountered in the high-pressure fracturing market. System developments also included the FracPort to be placed between the RockSeal Packers to deliver effective fractures along the horizontal wellbore.

More than 600 successful systems have been deployed in horizontal open-hole wells. The system's versatility is evident in its application span and the ability to design the stage length at the rig site and place the components to optimize the fracture for a particular zone or segregate a nonproductive zone. By pumping fractures or stimulations in the horizontal wellbore in one day, the well can be placed on production weeks earlier.

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