SPE-171183-MS

Single-Size-Ball Interventionless Multi-Stage Stimulation System Improves Stimulated Reservoir Volume and Eliminates Milling Requirements: Case Studies

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This paper was prepared for presentation at the SPE Russian Oil and Gas Exploration and Production Technical Conference and Exhibition held in Moscow, Russia, 14–16 October 2014.

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Abstract

In the last decade, there has been a tremendous growth in multi-stage fracturing for unconventional plays employing stimulation sleeves with open hole (OH) packers or cementing. Standard ball-activated frac sleeve systems with graduated ball seats have primarily been used because they can significantly save completion time and cost by facilitating the performance of multiple stimulations in a single continuous process compared with the conventional Plug and Perforate (P-n-P). However, traditional ball-activated frac sleeves have limitations in the number of stages that can be handled, the pressure drop and friction loss each one creates and the need to mill through the ball seats after stimulation. As the number of frac stages increases, the ball seat sizes become dramatically smaller leading to large increases in the surface treating pressure and hydraulic horse power (HHP) needed to generate a given net downhole pressure or injection rate.

To solve these limitations a revolutionary ball-activated fracturing system has been designed. This system behaves in similar fashion of activation to the traditional graduated ball seat frac sleeve in that the ball locks into place on the seat, but all the ball seats are the same size and retract, allowing the first ball to pass through all sleeves until it reaches the lowermost one. Similarly the next ball, which is the same size, lands on the next seat up and so on, allowing a virtually unlimited number of zones to be treated for either OH or cemented application. With this new system, there is no milling operation involved and the completion string maintains full drift inside diameter (ID) ready for production after stimulation operations have been completed.

In this paper the authors will describe in detail the operational mechanism of this new frac sleeve and present case studies of its use which illustrates the effect of this new technology in optimizing fracturing operations both in horsepower requirements and overall completion time and cost.

Introduction

There is a lot of debate about how best to complete and fracture unconventional formations regarding the effectiveness and efficiency differences between frac sleeve and P-n-P methods. Generally speaking, P-n-P is a time-consuming frac technique, due to the need for running Tubing Conveyed Perforating

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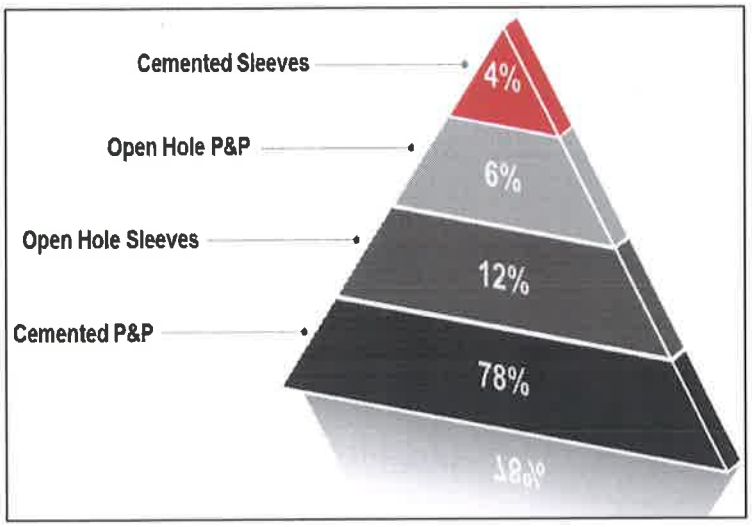

Figure 1—Percentages for different frac methods at Weatherford.

(TCP), Coiled Tubing (CT) and downhole tractors, etc. However, P-n-P is still the number one stimulation technique being used in unconventional horizontal wells in North America and globally. P-n-P is considered to be an effective and flexible multistage fracturing technique for individual stimulation across laterals, because each stage can be perforated and treated optimally with fracturing design changes before guns are fired. Many operators choose P-n-P to complete their wells because they are familiar with it and consider it to be a low risk option

However, openhole multi-stage (OHMS) completion techniques (frac sleeves + OH packers) are becoming more common in both North American unconventional plays and globally; for instance, OHMS techniques are the primary completion method for most new drilled shale/tight gas wells in the Bakken formation. The ball drop type of frac sleeve is well known to be a more efficient frac method and uses an "on-the-fly" method of isolating below the sleeve, opening a port, fracturing and then moving to the next zone, as well as being repeatable and reliable. The major advantage of frac sleeve is that all frac treatments can be performed in a single trip, with a continuous pumping operation without the need for a rig or CT or Wireline (WL) intervention. Dissolvable balls have already been used which will not impede production and could eliminate costly well intervention to drill out stuck frac balls. Figure 1 shows the distribution in percentages for different frac methods used in operations performed by Weatherford which reflect closely the overall distribution throughout the industry.

In principle, the P-n-P option can be more effective in individual stimulation across the laterals and the conventional frac sleeve option can be more efficient by completing more stages in less time. However, both methods have their drawbacks, the former requiring multiple re-entries and mill out operations, the latter having a limited number of fracturing stages due to the graduated seat sizes needed and the probability of the need of milling out the seats upon completion to remove flow restrictions. With frac sleeves, operators need to weigh the advantages in efficiency against potential operational risks such as premature sleeve opening or screen-out. With P-n-P, they need to compare the advantages of more effective interval coverage against the increased time required to complete the entire lateral.

In general, major benefits associated with OHMS against P-n-P can be summarized by elimination of the following operations and occurrences (Rivenbark et al. 2013):

- Eliminating TCP or CT perforation gun for the first stage before stimulation treatment begins.
- The time, equipment and cost associated with rigging up, running and rigging down WL for bridge plug (BP) and perforation operations.

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- The milling out of BPs after the stimulation and flowback.
- Misfires from P-n-P operations.
- Reduction of equipment and personnel on location, reducing overall HSE exposure.
- No well intervention during stimulation.
- Stimulation treatment involving the entire lateral allowing natural fractures to contribute to production.

Figure 2—Floppy latch-down wiper dart.

Challenges in Hydraulic Fracturing

With longer lateral sections drilled in horizontal wells for unconventional resources, more frac stages will be needed to optimize the fracturing design and increase production. The effectiveness of hydraulic fracturing is the key to both successful initial production and long life for the wells. Operators report that not all perforated clusters in P-n-P treated wells are producing. One study shows that about a third of all perforated clusters do not contribute to production and also the uneven stimulation indicates uncontrolled frac dimensions (Miller et al. 2011).

The industry has realized the efficiency and economic advantages of using frac sleeves, but conventional ball drop frac sleeves have graduated ball seats that limit the number of frac stages and add treatment pressure drops through them during operations. This will require an increase in surface pumping pressure to achieve planned fracturing rates. In addition, the milling-out of ball seats may be required to remove flow restrictions and achieve higher production rates (Wozniak, 2010). In terms of hydraulic fracturing, OHMS has less control over frac initiation points, frac length and frac placement. Also, completion tools like hydraulic set OH packers and even the liner itself may induce stress and create frac initiation points (Daneshy, 2011). In some cases, reservoir conditions may dictate a cemented completion, because packers cannot withstand the high temperature or suitably sized OH packers are not available.

To take full advantage of sleeves for longer frac and more control over where fracturing initiates, one of the most significant innovations of the cemented completion may be the opportunity to use cemented frac sleeves activated with balls or CT. Some studies have shown that production comparisons between P-n-P and cemented sleeve completions show little difference. Also, using microseismic mapping and oil soluble tracers together, the single entry point provided by the sleeve option did not hamper production when compared to the multiple entry points of the P-n-P approach (Stegent et al. 2013; Adcok et al. 2013 and Bozeman et al. 2009). However, the cemented conventional ball-drop frac sleeves have graduated ball seats and result in limitation of the number of frac stages. Efficient cement displacement is vital in the tapered string of a ball drop sleeve completion and a long multi-finned floppy latch down wiper dart in Figure 2 is often used and can pass through a ball seat ID of 2.063″ based upon the lab testing.

By comparing the advantages and disadvantages between P-n-P and conventional ball drop frac sleeves, the improvements that are needed to enhance current the results from multistage frac systems are as follows:

- No limitation in the number of frac stages for OH or cemented sleeve application.
- Lower surface pressure to minimize HHP needs.
- Monobore completion to reduce pressure losses.

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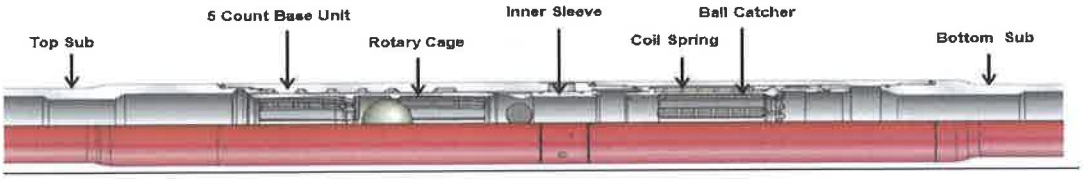

Figure 3—Main items of this new frac sleeve.

- Elimination of intervention requirements.
- Reduction of equipment, manpower, traffic and time on location to enhance HSE considerations.
- Reduction of overall costs.

New Frac Sleeve introduction

To address the limitations of the conventional graduated-seat multistage frac system, an unlimited and intervention-less multistage ball-activated fracturing system has been developed which provides a viable alternative to both the P-n-P and conventional ball-drop frac sleeves. This new sleeve is a ball-activated frac sleeve with single size balls and ball seats for all stages, which allows an essentially unlimited number of frac stages and is the only single size ball intervention-less frac sleeve system currently available for OH and cemented fracturing completion.

Operational mechanism

To explain how this new sleeve works, the sleeve with 5 count base unit is chosen as an example in Figure 3. The main items of this new frac system include: 1) The Top Sub, 2) The 5 Count Base Unit, or with Extension Count Subs, 3) The Rotary Cage, 4) The Inner Sleeve, 5) The Coil Spring, 6) The Ball Catcher, and 7) The Bottom Sub. To achieve unlimited fracturing multistages, this new frac sleeve has three (3) distinct sections: 1) The Rotary Cage pre-positioned in a sub with a series of recesses, 2) The Inner Sleeve and 3) The Ball Catcher to isolate the lower stimulated zone.

To illustrate the operational mechanism, this new frac sleeve with the 5 Count Base Unit and the Rotary Cage pre-positioned in 5 count position (the uppermost recess) is chosen to describe how this system works. When the four balls separately advance to the Rotary Cage and move it along a series of recesses, these balls are counted before continuing downhole to next sleeve. Since the Ball Catcher is not seated yet, 4 (four) balls can pass through the sleeve. Finally, when the Ball 5 advances the Rotary Cage, it will push it to shift open the Inner Sleeve to overcome shear value of shear pins. When the Inner Sleeve slides open, it simultaneously activates the Ball Catcher to form a ball seat so that the ball is caught on the seat to isolate lower zone, and the zone is ready for frac stimulation (Yuan et al. 2013). Figure 4 shows an overview of how the ball pushes and passes the Rotary Cage which shifts open the Inner Sleeve and simultaneously activates the Ball Catcher to form the ball seat Based on the number of frac stages, Extension Count Subs can be added right below the Top Sub to suit clients' needs.

Benefits versus current frac completion methods

This new frac sleeve behaves in similar fashion to the graduated ball seat frac sleeve in that it is activated by dropping a ball for each zone, but it has a unique design which can make single size balls pass through all retractable ball seats thus precluding the need for a seat milling-out operation. The retractable ball seat also comes in handy in the event of screen-out, because pulsing the well allows the ball seat and ball to retract, the ball can then fall through the seat and the sand washes away and the operation can continue. While conventional graduated-seat designs require different-sized balls and seats for each separate zone, this new ball-drop system is different, using a single ball size throughout the entire well enables stimulation of a virtually unlimited number of zones. In addition, because there aren't ball seats to mill

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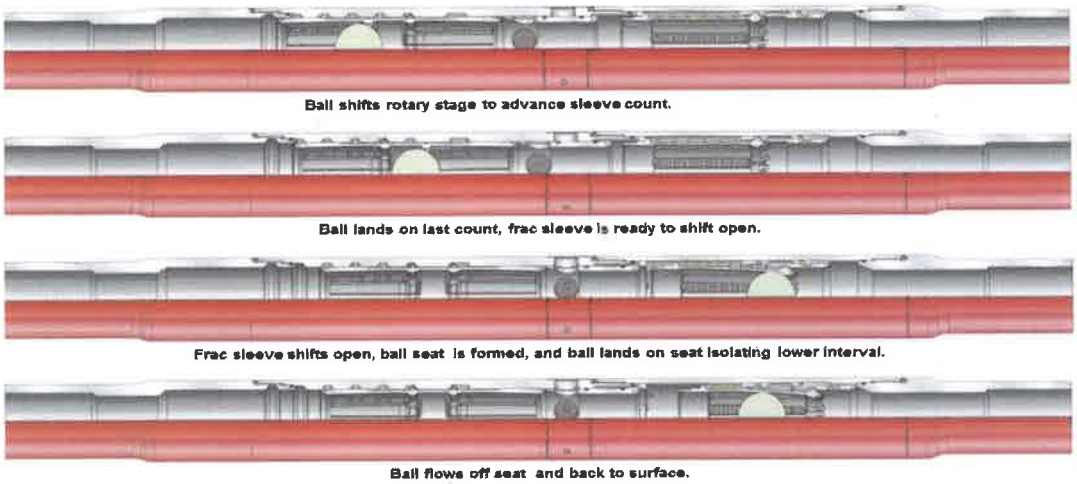

Figure 4—An overview of operational mechanism for the new frac sleeve.

out, time-consuming interventions can be eliminated reducing the number of people and the amount of equipment needed on site to allow the job to be done faster and more efficiently.

There are plenty of benefits to using one ball size throughout the well:

- No risk of sending the wrong-sized ball downhole and actuating sleeves out of sequence
- No more need for costly and planned milling operations
- No risk of prematurely actuating ball seats due to stimulation pressure
- A near-monobore completion from top to bottom, which minimizes downhole pressure drops
- Improved flow efficiencies, so less topside horsepower is needed to maintain an effective stimulation

Compared to other methods of multistage stimulation, this new sleeve delivers significant savings potential. For instance, at 40 stimulated zones (the limit of graduated-seat sleeves), this new sleeve is very cost competitive with technologies that take longer and require costly intervention, etc. Compared to a P-n-P operation with a toe sleeve, the total well cost of this cemented new sleeve is at least 18% lower (Yuan et al. 2013).

Using the same horsepower to stimulate from toe to heel, graduated-ball sleeves are far less efficient at the toe. This new sleeve, however, provides a uniform bore and delivers a much more effective stimulation as pressure and friction loss are dictated solely by lateral length, not by ball-seat restrictions.

Used in an OH application, this new sleeve is the most efficient multistage stimulation option available, and compared to a P-n-P system with TCP, the new sleeve reduces onsite-services requirements by as much as 66 %.

Advantages versus sleeve systems with graduated ball seats:	Advantages versus plug-and-perf systems:
• Eliminates milling of ball seats • Increases the number of production zones • Decreases horsepower requirements • Enables screen-out recovery with no need for intervention • Eliminates risk of pressure-actuating ball seats • Reduces surface equipment and site size • Reduces the number of onsite personnel • Reduces logistical activities	• Eliminates milling • Reduces time on site • Accelerates operations • Reduces water usage up to 30 percent • Reduces logistical activities • Reduces the number of onsite personnel • Decreases overall capital expenditures and operational cost

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