Building a Re-Frac-Ready Completion

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Abstract

As operators continue to learn about unconventional resource plays, we know much of the hydrocarbon is left unrecovered in the wellbore even after stimulation. This has given rise to interest in re-fracturing of unconventional wellbores, which recently has shown it can bring wells back to near initial production levels and provide additional reserves. This article discusses how a re-frac ready wellbore can be constructed using current multistage completion technology.

The majority of unconventional wellbores are designed in a manner to enable only the most effective primary stimulation with little regard for potential re-fracturing needed in the future life of the wellbore. Unconventional wells typically use a plug-and-perforate completion method, which creates multiple holes in the production casing before fracturing takes place. However, recloseable multistage fracturing sleeve systems can be used to not only enable a successful primary fracture treatment but also facilitate the re-fracturing of wellbore in the future. These fracturing sleeves have been designed so that they can be closed and opened multiple times throughout the life of the wellbore, providing additional flexibility in wellbore construction.

This article discusses how a re-frac-ready wellbore using recloseable multistage fracturing sleeve technology can be created. A re-frac ready wellbore can both optimize the primary fracture treatment and help permit re-fracture options with minimal intervention. The testing of this type of fracturing sleeve technology is also reviewed to highlight the viability of the solution. The recloseable multistage fracturing sleeve completion will be contrasted against the current plug-and-perforate completion method to highlight enhanced efficiencies and operational flexibility. This article also provides examples of operations using this type of completion system. Conclusions are drawn based on the data reviewed, potential impact of this type of completion system, and the potential of this type of technology to enable re-fracturing.

Challenge

Within the past decade, unconventional resources development in North America and around the world has increased at a staggering pace. This has been attributed mainly to advances in oilfield technologies, such as horizontal drilling and hydraulic fracturing both of which are commonly used to make unconventional resource development economical. However, for the majority of unconventional resource targeting wellbores, overall hydrocarbon recovery is low. This leaves much of the potential reserves left to be recovered. It also increases the importance of the portion of the wellbore affected by hydraulic fracturing or what is referred to as stimulated reservoir volume (SRV), Mayerhofer et al. (2010). Increased SRV often proves to be key to optimization of well production. Another property of unconventional wells is their typically much steeper decline curves as compared to conventional formations. Both of these factors contribute to the potential necessity for unconventional wellbores requiring re-fracturing at some point in their life cycle to revitalize well production and potentially tap previously untapped hydrocarbons in place. The latter can add to the estimated ultimate recovery (EUR) of the wellbore.

In addition to the nature of unconventional reservoirs, these formations are typically produced through horizontal wellbores drilled through the "sweet spot" of the target formation, Hashmy et al. (2012). The goal is to hydraulically fracture the sweet spot portion of the target formation as it is thought to provide the potential for maximum production, Sahoo et al. (2013). The primary hydraulic fracturing treatment can be performed with a variety of completion methods. However, most commonly a plug-and-perforate completion technique is applied, which uses a combination of wireline-deployed fracturing plugs for fracturing stage isolation and perforating guns to create perforations to access the target zones of the formation. The plug-and-perforation completion technique does have certain inherent inefficiencies, Ferguson et al. (2012). The other common option uses ball-drop fracturing sleeve (BDFS) completion systems. A BDFS completion system is installed as part of the production casing string. Access to the target formation is achieved by dropping balls from surface which activate each BDFS, providing access to the formation and isolating the target BDFS from previous stages. BDFS completion systems often reduce the fracturing cycle time over the plug-and-perforate completion technique, Fruge et al. (2013). Either of these primary completion systems can be used with cement or openhole packers for annular isolation of fracturing stages. The disadvantage of both systems is that multiple permanent entry points are created in the production casing string. With the plug-and-perforate completion technique, several perforation entry points are created per target fracturing stage with multiple perforations per entry point over dozens of target stages along the length of the lateral section of the wellbore. This amounts to hundreds of individual perforations in the production casing. With the BDFS system, one-time open BDFS are typically installed in the production casing string. This means once opened, the sleeve cannot be closed and essentially acts the same as a set of perforations. The multiple permanent perforations with either type of completion method create a variety of challenges to successful re-fracturing of the wellbore.

What if a primary completion system that considered re-fracturing could be installed so re-fracturing could be effectively accomplished later in the life of the well?

Background

Though used in the majority of unconventional wellbores, traditional plug-and-perforation techniques present challenges to both efficiency and the ability to re-fracture. Wells completed using the plug-and-perforate technique can limit re-fracturing options and increase their cost, potentially making them uneconomical. In addition, the number of perforations in the wellbore can cause issues with the effectiveness of re-fracturing efforts. The same can be said for BDFS systems, which can only be opened once. However, completion technologies exist today, which can be deployed during the primary completion and not only deliver effective primary fracturing of the wellbore but also allow for re-fracturing in the future. Recloseable fracturing sleeve (RCFS) systems or remotely operated fracturing valves (ROFV) support effective creation of a re-frac-ready wellbore before completion. These technologies can be deployed as part of the production casing string and either cemented in place or isolated by openhole packers to provide fracturing stage annular isolation. The systems have the added feature of being able to be closed and re-opened for a variety of applications, such as re-fracturing, inflow control, production evaluation, etc., enhancing the flexibility of the primary completion methods use beyond primary fracturing of the target formation. The RCFS system is available in two versions: mechanically operated or ball-drop open/mechanically closed. The RCFS system then uses intervention with coiled tubing (CT) or jointed pipe (JP) and a mechanical shifting tool to close and open sleeves for re-fracturing operations. ROFV uses hydraulic control lines run along the side of the casing string. By applying or releasing pressure from surface on the control lines run attached to each ROFV, the ROFV can be operated open or closed for re-fracturing applications.

Technology Discussion

Sliding sleeve technology and remotely operated valves are not new to the oil field but were new to the harsh wellbore environments created during hydraulic fracturing operations necessary in unconventional resource plays. These legacy technologies were primarily used for inflow control or production purposes. This necessitated advances be made in the tool designs to handle the new and rapidly evolving requirements created by hydraulic fracturing through the sleeve and the rise in development of unconventional resources. Both technologies would have to employ designs that could handle the erosional effects of high pump rates varying proppant concentrations, large amounts of proppants pumped, the use of acids and stimulation fluid chemicals, and increasing fracturing stage counts, just to name a few. Added to these conditions created by the primary fracturing treatment, the tools would also have to be able to be opened and re-closed post-stimulation for re-fracturing and other applications.

Recloseable Fracturing Sleeve Technology

The first version of the RCFS suitable for fracturing applications was developed in 2006 in a ball-drop operated version. As mentioned, the first generation RCFS sleeve was derived from legacy sliding sleeve technologies combining the best of existing designs; then, optimizing the design for harsher fracturing environments. This included a ball seat for ball-drop activation of the sleeve, improved design elements to combat potential erosional effects from proppant, and testing of the frac balls used to activate the RCFS to ensure they could stand up to the pressure and conditions of the fracturing treatment. Applications of the first-generation RCFS were primarily in North American unconventional plays to help improve operational efficiencies or to provide for the potential necessity of inflow control of unwanted production. However, the economics of unconventional well completions progressed to favor the use of more economical BDFS systems that did not contain the ability to open and close the sleeves. As unconventional resources began to be discovered internationally as well as the desire for operators to use BDFS offshore, interest in RCFS systems increased due to the additional flexibility offered by this type of system. RCFS system became a preferred completion method leading to an evolution in the RCFS design. The RCFS design was carefully evaluated and technological improvements were identified to enhance its performance. The technological improvements were designed to meet new demands brought on by the evolution of unconventional resource development and fracturing throughout North America as well as offshore applications and international unconventional plays. The second-generation RCFS was simplified for assembly, operation, and handling.The RCFS tool reliability and robustness was improved by applying lessons learned and enhancing the RCFS design. The first design feature that was enhanced was the length of the RCFS. Adapters connecting different parts of the first-generation sleeve body were deemed unnecessary and removed making the tool easier to assemble and eliminating some length which operationally makes the second-generation RCFS easier to install in a wellbore. Next, the internal elastomers were improved giving the second-generation RCFS the ability to be shifted closed or opened in both an overbalanced and underbalanced application without compromising the integrity of the seals. This widened the operational range of the tool during shifting operations as well as empowered long-term sealing reliability of the RCFS through shifting operations. Another enhancement in the second-generation RCFS was a change in the lead in angles on the inner sleeve. This made it easier to locate the mechanical shifting tool used to open and/or close the RCFS into the shifting profile. The second-generation RCFS was then vigorously qualified and tested to verify the effectiveness of the enhancements. The second-generation RCFS has two versions: ball-drop operated for opening and then mechanically shifted closed/re-opened and a mechanically shift only.

Figure 1. *Ball-drop operated RCFS example.*

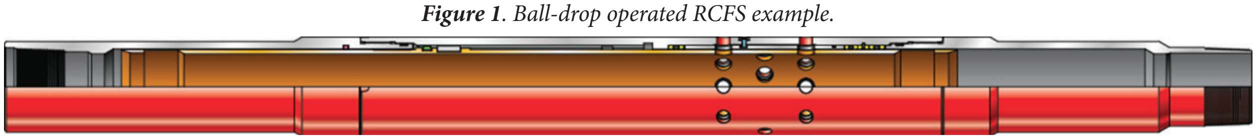

Figure 2. *Mechanically operated RCFS example.*

Qualification and testing of the second-generation RCFS included a rigorous course of pressure tests and open/close cyclical verification testing at a multitude of temperatures and conditions. This verified the unique seal design that is supported in the worst-case scenarios to offer reliable sealing through multiple pressure cycles and shifts in both over and underbalanced conditions. The enhanced seal design assists staged unloading of the seals for increased reliability and assurance the sleeve will hold pressure when shifted throughout its lifetime. Cement testing was also performed to verify the RCFS could be used with this type of annular isolation. Cement testing additionally qualified the correct cementing equipment to enable effective cementing of an RCFS system. This ensured both primary fracturing and shifting of the sleeves post-fracturing could be achieved with cement as the annular isolation method. Heavy erosion testing was also conducted to simulate real-world downhole conditions and prove RCFS design durability. Millout and drillout testing completed on the ball seats in the ball-drop operated version of the RCFS verified best practices and recommendations for wellbore preparation before sleeve shifting operations.

Operational function testing of the second-generation RCFS was also conducted on a flow loop in which the frac ball to activate the ball-drop operated RCFS was pumped around the flow loop to land on the ball seat and open the tool. Additionally, mechanical shifting tests with multiple styles of shifters were all conducted to verify every operational aspect of the tool and test effectiveness of the design enhancements. For final verification of the overall system, a full systems integration test (SIT) was completed on a fully working rig with a horizontally drilled wellbore. This allowed for testing of multiple operational scenarios on the RCFS systems and RCFS shifting tools before being released for field applications.

Recloseable Fracturing Sleeve Shifting Tools

To shift the RCFS into either an opened or closed position depending on the version of the RCFS used, hydro-mechanical shifting tools are used. There are two versions of the RCFS hydro-mechanical shifting tools available: standard and high expansion (HE). These shifting tools are selectively activated by flowing down the CT or JP, or in the case of electric wireline (e-line), a specially designed shifting tool is used. The fluid flow then creates a backpressure to activate the keys on the shifting tools. The keys on the hydro-mechanical shifting tools can then engage a shifting profile on the inner sleeve of the RCFS, or in the case of the HE shifting tool, the ball seat of the RCFS. This allows the RCFS to be shifted into a different position. The design of the shifting tools allows the operator to shift multiple sleeves in a single trip selectively, shifting the ones desired while skipping others without engaging all sleeves in the wellbore. In the case of re-fracturing operations, each sleeve can be closed and then re-opened for fracturing operations. Once completed, all RCFS can be opened in a single trip to bring the well onto production.

Figure 3*. Standard hydro-mechanical RCFS shifting tool example.*

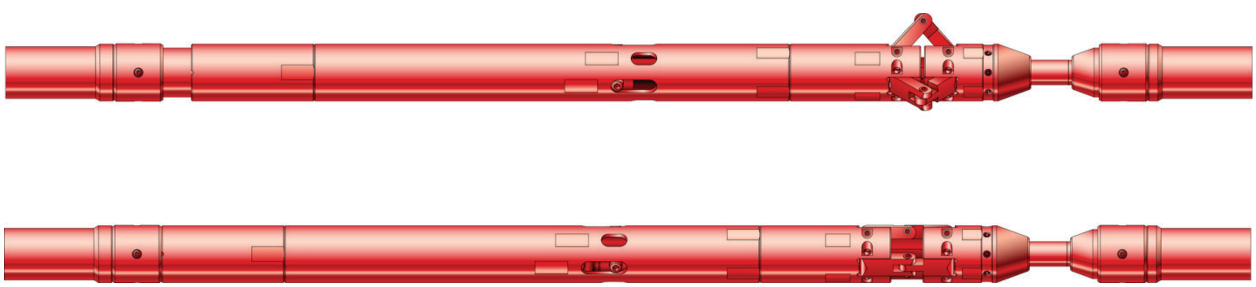

Figure 4*. HE RCFS shifting tool example.*

Remotely-Operated Fracturing Valve

The ROFV provides an additional potential option to engineer a re-frac ready wellbore. The ROFV allows selective fracturing of multiple stages in a wellbore without the need for mechanical intervention or to drop frac balls from surface. Through the use of control lines run from the surface, ROFVs can be remotely operated by either applying or releasing pressure to open and close target valves. This enables each target stage to be selectively fractured. Once fracturing has been completed, all the ROFVs can be opened to allow wellbore production. ROFV have a large fullbore ID which eliminates restrictions in the wellbore and potential pressure drop that can be created during fracturing as a result of the restrictions. During qualification testing, ROFV were tested for pressure capabilities, erosional resistance, and the ability to handle high flow rates required for fracturing unconventional completions. Additionally due to the ability for the ROFVs to be operated remotely, the ROFVs can be functioned at regular intervals for preventative maintenance throughout the life of the well. This encourages the ROFVs to function properly when they may be needed for re-fracturing operations. This can help prevent the long term buildup of scale, paraffin, solids, or other materials that could impair the ROFV function. Re-fracturing operations with the ROFV are achieved in the same manner as primary fracturing operations.

Figure 5*. ROFV example.*

Completion System Operations

ROFV System Operations

As previously mentioned, ROFV systems use valves installed as part of the production casing, with control lines run along the length of the casing string to operate the valves. During fracturing operations, pressure is applied down the control to the target valve. Then, the valve opens; thereby, the target stage can be fractured. Once the fracturing treatment has been pumped successfully, pressure is released from the control line to close the target valve. The process is then repeated for each of the next ROFVs until the well has been completely fractured. When fracturing completes, pressure is applied to all control lines and held to open all the ROFVs and produce the well. Typically, a maintenance program of cycling the ROFVs is followed during the life of the well to ensure ROFV functionality. At some point in time when the wellbore declines and is in need of re-fracturing, pressure can be bled from the control lines to close all the ROFVs, and the fracturing process can be repeated in the same manner as the primary fracturing treatment. The ROFV system provides potential for re-fracturing operations and several advantages, such as remote operations, no requirement for dropping ball into the fracturing fluid stream, high fracturing rates, and large unrestricted ROFV ID. However, the ROFV and control line can significantly impact the cost of the wellbore completion. Additionally, the use of control lines and associated technologies can limit the number of ROFVs that can be run in a wellbore. Because unconventional well developments are cost sensitive to ensure acceptable returns and the trend in unconventional wells is toward more fracturing stages per well and longer laterals, the ROFV system is not a commonly deployed completion method for an unconventional well. However, with the attractive features and advantages of a ROFV system, more technological development could facilitate ROFV system application in unconventional completions and for the creation of a re-frac-ready wellbore.

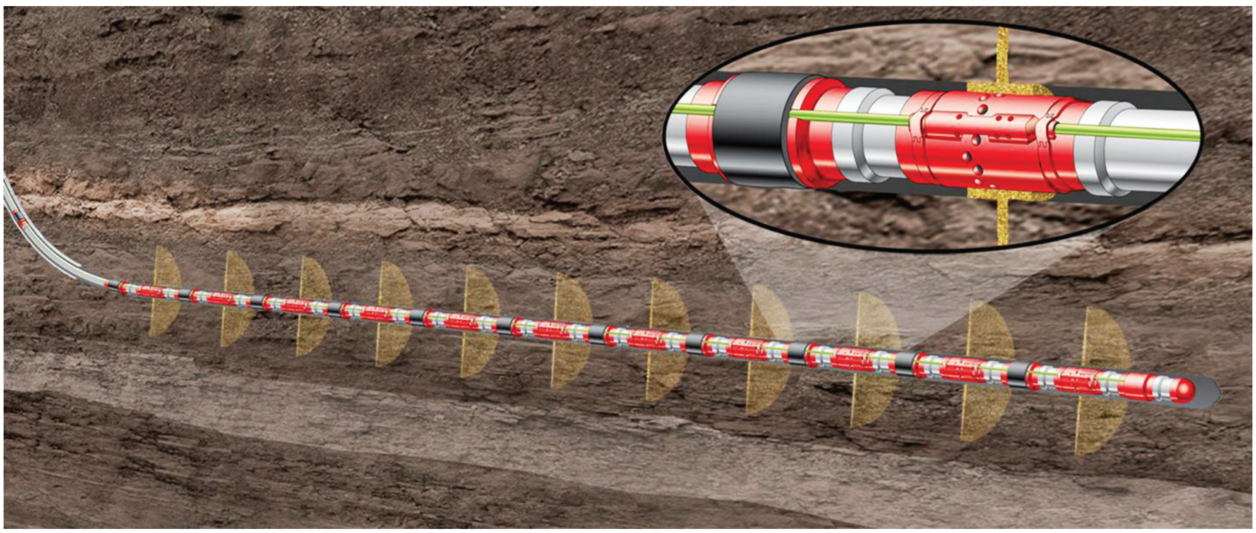

Figure 6. *ROFV completion system example.*

As discussed, the RCFS system builds on the BDFS system technology and other sliding sleeve technologies, which possess the added feature of being opened and closed multiple times during the life of the well. BDFS systems have provided equivalent production to plug-and-perforate completions in certain unconventional resources plays, Stegent et al. (2011), highlighting BDFS system viability as a primary completion option. The primary difference operationally between a BDFS completion system and RCFS systems, outside of the recloseability of the RCFS system, is the RCFSs can be configured for mechanical-only operation or opening using a surface ball-drop method for primary fracturing.

Mechanically Operated RCFS System

The mechanically operated RCFS system is run as part of the production casing string, has a full open ID, and an unlimited number of RCFSs can be run in a single well. The system can be cemented in place or used with openhole packers for annular isolation of the RCFS system. Once run in place and fracturing is ready to begin, the shifting tool is run into the wellbore on CT, e-line, or JP. When the shifting tool reaches the depth for the target RCFS, the shifting tool is activated by different methods dictated by how the shifting tool was deployed into the wellbore. Keys in the shifting tool then locate a profile in the target RCFS, and the sleeve is pulled open. The shifting tool is then removed from the wellbore or at least pulled back into the vertical section of the wellbore; thereby, the fracturing treatment can be pumped. After fracturing has completed, the shifting tool is then deployed back into the wellbore. This time the shifting tool uses a pushing force to close the target RCFS that was just fractured. In the same trip, the next RCFS can be opened to prepare it for the next fracturing treatment. This process is repeated for each RCFS run as part of the completion string. When all the RCFS have been successfully stimulated, one more trip is made with the shifting tool to open all RCFSs in the wellbore to enable production of the well.

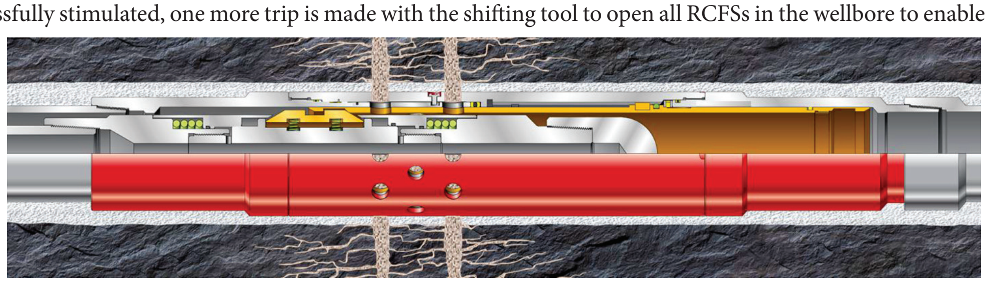

Figure 7. *RCFS with mechanical shifting tool engaged.*

Re-Frac Operations with Mechanically Operated RCFS System

Re-fracturing operations with the mechanically operated RCFS system can be accomplished in the same manner as primary fracturing jobs. The shifting tool is deployed on CT, e-line, or JP and used to open, stimulate, close; then, re-open the entire target of RCFSs to be re-fractured. Field examples of shifting the sleeves post-stimulation and after they have produced for some time has shown additional force can be required to operate the RCFS. This can be caused by not running a wellbore cleanup before shifting, proppant or other solids remaining in the wellbore, paraffin or scale buildup, fluids left in the wellbore that do not contain a corrosion inhibitor or other needed production chemicals, or a variety of other reasons. As a result, the use of tools that can provide additional shifting force, such as a downhole force generating tool or stroker tool are recommended to be included in the bottomhole assembly (BHA). The use of impact hammer tools is typically not preferred as the action created by the hammer can cause the keys in the shifting tool to disengage from the profile in the target RCFS; thereby, affecting the ability for the RCFS to be successfully operated. Additionally, torque-and-drag modeling is recommended to verify the amount of force available for shifting when CT or JP is used in conjunction with the shifting tool BHA.

Ball-Drop Operated RCFS System

The ball-drop operated RCFS system contains sleeves, which have a ball seat installed in the inner sleeve. The ball seats are graduated in size and correspond to a specifically sized frac ball that will land on the ball seats to activate each target RCFS. This RCFS system type is also run as part of the production casing string and can be used with either cement or openhole isolation packers for annular isolation of fracturing stages. However, it is limited in the number of maximum fracturing stages that can be achieved by ball-drop activation, and each RCFS has an ID restriction created by the ball seat installed in each RCFS. During the primary completion process, the RCFS system is run to target depth and set in place by cementing or with the use of openhole packers. Once fracturing operations are ready to begin, a frac ball is released into the stimulation fluid stream that corresponds in size to the size of the ball seat for the first target RCFS. The frac ball travels down the wellbore until it reaches the ball seat in the target RCFS. The frac ball then seals on the ball seat, and increased pressure opens the target RCFS. The frac ball then serves to divert the flow out exit ports in the RCFS and also isolate the target RCFS from those previously stimulated below it. The ball-drop process is repeated for each RCFS in the completion string until the fracturing operations for the wellbore have completed. After fracturing, the frac ball can either flow back to surface or in some cases degrade completely depending on the type of frac ball used during the completion process.

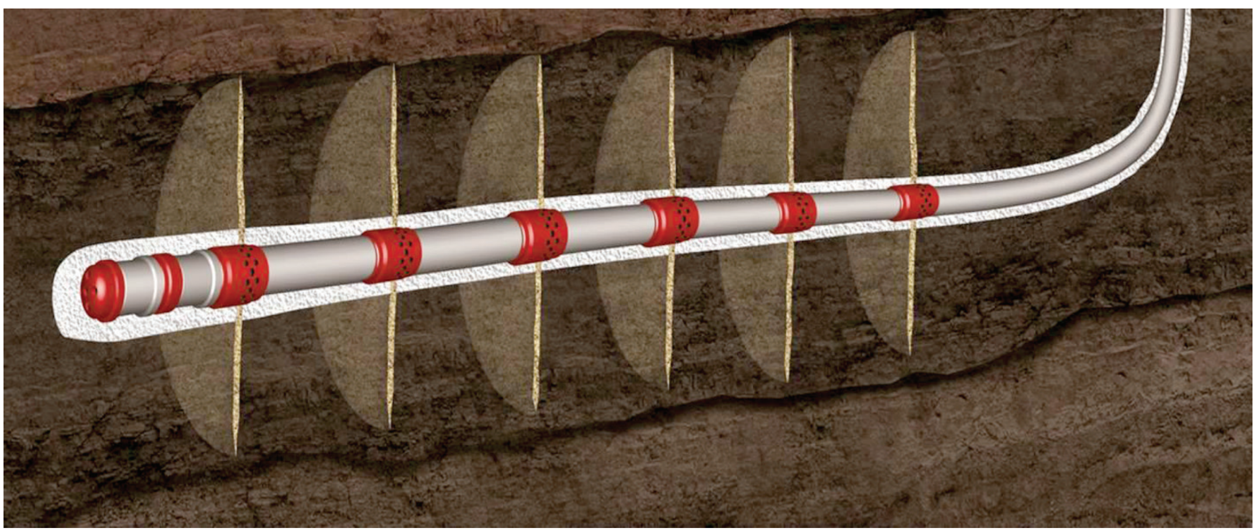

***Figure 8**. RCFS system with cement annular isolation example.*

Re-Frac Operations with Ball-Drop Operated RCFS System

With the ball-drop operated RCFS system, re-fracturing operations are possible by two different methodologies. Using the first method, a milling BHA is run into the wellbore on CT, e-line, or JP, and the ball seats in each RCFS are removed by the milling process. Once the ball seats in the RCFS have been removed and the wellbore cleaned out, re-fracturing operations is able to commence in the same manner as described for the mechanically operated RCFS system. Additionally, the same considerations and recommendations apply.

The second method uses the HE shifting tool BHA to close all the RCFS. This is performed in a single trip by running the HE shifting tool to the bottom of the RCFS system using either CT or JP. The first RCFS is located using depth measurements accounting for the stretch caused by temperature on CT or JP. When the sleeve is located, the HE shifting tool is positioned below the target RCFS and is activated by pumping through the CT or JP to create a pressure drop and expand the keys. The HE shifting tool is then pulled up, and the keys engage the bottom side of the ball seat inside the target RCFS. The sleeve is then pulled closed. Pressure is released allowing the keys to relax, and the HE shifting tool BHA is moved to the next RCFS. The process is repeated to close all the RCFS in the completion string effectively resetting the entire completion system. The HE shifting tool BHA is then removed from the wellbore. Fracturing equipment is then moved in, and the ball-drop process used to activate each of the RCFS during the primary completion is repeated to re-fracture each RCFS in the completion string. Using this method for re-fracturing operations increases efficiency by enabling the use of a ball-drop process during stimulation operations. However, the OD of the tools used in the HE shifting tool BHA further limits the number of RCFS that can be run. Also, the amount of force that can be used to pull the RCFS sleeves closed with the HE shifting tool BHA is less than with the standard shifting tool; therefore, shifting tension must be monitored during operations, and the use of hammer-type tools for additional force is not recommended. When the HE shifting tool BHA is used, torque-and-drag modeling is also recommended to verify the amount of force available for shifting and model downhole conditions while shifting the RCFS.

Conclusion and Impact

Wells targeting unconventional resource plays typically experience lower hydrocarbon recovery rates and steeper decline curves than conventional formations. This often necessitates the use of re-fracturing techniques to bring wells back to original productive levels and increase EUR. Plug-and-perforate and BDFS are the most commonly used primary completion techniques for unconventional wells. However, both create challenges for re-fracturing of an unconventional wellbore later in its life cycle.

Re-frac-ready wellbores can be created using alternative completion methods employing either ROFV or RCFS systems. ROFV systems are currently more costly than the commonly used completion techniques and cannot provide the stage count requirements of modern unconventional wells. Technological advancement of this type of system will be necessary for it to meet the requirements of unconventional wellbores. However, RCFS systems can often provide a viable option to create a re-frac-ready wellbore to be used in unconventional wellbores. RCFS systems can often provide the needed stage count and enable efficiency gains assisting in making these types of systems economical completion options, Fruge et al. (2013). Additionally due to technological advancements, RCFS can facilitate the flexibility to open and close the sleeves multiple times throughout the life of a wellbore. RCFS have been designed with many specific features to allow the long term potential functionality of these sleeves. RCFS have been successfully shifted to both control inflow of unwanted fluids and individually production test specific fracturing stages successfully in field applications. During these operations, it was discovered after being in a wellbore for some time additional shifting force is typically required to successfully function the sleeves for a variety of reasons. However, these examples plus the enhanced design features of the RCFS and lessons learned from shifting operations show RCFS systems can provide both primary fracturing treatments and the re-fracturing of unconventional wellbores.

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Biographies

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Cody graduated from Texas Tech University in 2007 with a Bachelor's of Science Degree in Mechanical Engineering and a minor in Mathematics. He is a member of SPE and regularly conducts internal and external training for the further advancement of Unconventional Completions.