

Retrievable Fracturing Sleeve System and Chemical Diversion Packer for Multi-Stage Re-Stimulation of Unconventional Wellbores

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Abstract

With the growing number of unconventional resource targeting wellbores that are experiencing production declines, re-fracturing operations can bring renewed production to a well, enhancing overall recovery. However, for any re-fracturing process to bring value to the industry, the process must accomplish key goals. Such goals include creating meaningful production increase, ideally across the entire target pay zone, and ensuring the method used brings a rate of return justifying the investment in the re-fracturing operation.

This paper discusses a retrievable service string, which uses specialized fracturing sleeves to allow re-fracturing of multiple zones along a single wellbore. The service string with the fracturing sleeve is run into the wellbore on a retrievable service packer. Once on depth, a chemical diversion packer is placed in the annulus to provide isolation and diversion of individual fracturing treatments. During the stimulation operation, each fracturing sleeve is activated sequentially by using a surface ball-drop method to allow for continuous pumping of the fracturing treatment. Once fracturing operations are completed, after a specific amount of time, the chemical diversion packer will degrade, allowing the service string to be retrieved from the wellbore. The retrievable fracturing sleeve system can then be redressed and reused in additional wellbores, providing a repeatable and economic re-fracturing system.

This paper highlights system components, design, and operation of the system. This includes the chemical diversion packer and retrievable fracturing sleeve technologies. Operational examples of this system are also reviewed, with focus on potential applications of this type of re-fracturing system and critical design factors. Conclusions are made based on the system design, repeatability, applications, and potential positive impacts of using this type of system in unconventional wellbores requiring re-stimulation.

Challenge

The pace of unconventional resource exploration and production has dramatically increased over the last decade, bringing about a new energy boom in many areas globally; particularly North America. However, unlike more conventional formations, unconventional reservoirs typically experience lower recovery percentages of hydrocarbon in place and steeper decline curves. These combined factors lead to the potential necessity for re-fracturing unconventional wellbores to both reinvigorate production levels and increase the estimated ultimate recovery (EUR) of the wellbore or asset. Because of the current depressed market conditions of the energy industry, oil and gas operators are now considering re-fracturing as one potential way to economically improve well production and return on investment. While several techniques now exist to help enable re-fracturing wellbores, each has a unique set of both advantages and disadvantages. Currently, the most common technique used for re-fracturing operations is degradable chemical diverting agents pumped into the wellbore with the re-fracturing treatment. However in most cases only part of the target interval of the wellbore is effectively re-fractured. This presents challenges with respect to identifying new methods or processes to re-fracture the entire length of the wellbore targeted for production and potentially further positively impact production levels and EUR.

Background

In an unconventional wellbore, the goal of a fracturing treatment is to stimulate as much of the target section of the reservoir as possible during the completion process. The amount of reservoir stimulated by the fracture treatment is often referred to as the stimulated reservoir volume (SRV), Mayerhofer et al. (2010). It is thought that higher SRV leads to higher production when the reservoir quality is good. Often, the goals of re-fracturing an unconventional wellbore remain similar—further increase the SRV to return the wellbore to a more productive level and/or repair near-wellbore (NWB) damage that has reduced wellbore productivity. This can be completed by re-fracturing through existing perforations or fracturing sleeves to contact new rock, or by creating new perforations and attempting to fracture these new sections of the formation in the same wellbore.

Several techniques currently are available to re-fracture an unconventional wellbore.

First, the “pump and pray” or “bullheading” technique can be employed, wherein the re-fracturing treatment is pumped down the wellbore, often at high rates, to stimulate the wellbore.

A second method is diverting agents, such as biodegradable balls, to seal off perforations, or degradable chemical diverting agents; Melcher et al. (2015); Allison et al. (2011); which seal off within the fracture to increase the pressure necessary to continue stimulating that fracture, and thereby

force the fracture treatment to move to a new part of the lateral. The earliest documented use of a diverting agent was in 1936 by using a soap solution that reacted with calcium chloride to form a precipitate; Harrison (1972). Using diversion techniques can require relatively high horsepower on location because the full target interval is being stimulated at the same time. However, because of the ease of operations, ability for chemical diverters to degrade post-stimulation, and effectiveness, this is the most commonly employed method for re-fracturing of unconventional wellbores. It is also currently considered to be the most economical method.

A third technique is a straddle packer bottomhole assembly (BHA) run into the wellbore on coiled tubing (CT) (**Figure 1**).

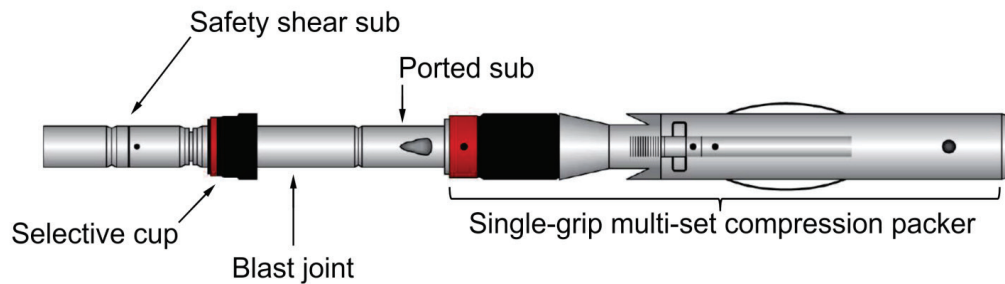


Figure 1. Retrievable straddle packer BHA used for re-fracturing operations.

The straddle packer BHA is then positioned across an existing set of perforations so that the straddle packer provides isolation on either side of the perforation; Romanson et al. (2011). The fracture treatment is then pumped down the CT and out the perforations for re-fracturing.

A fourth method for re-fracturing using a CT BHA exists, whereby the BHA is run into the wellbore. The target set of perforations is re-fractured and then a sand plug is set to provide isolation of the target stage and previous stages; Bonapace et al. (2009). The process is repeated and, when the well has been completely re-fractured, the sand plugs are washed clean with the CT BHA.

A fifth technique includes the installation of a new completion string inside the wellbore. The completion string often consists of a liner hanger, new casing sections or fracturing sleeves, and packers for isolation of individual stages. The system is then run into the wellbore and new sets of perforations are created in the casing, or fracturing sleeves are operated, and either is isolated by a set of packers. The fracture treatment is then pumped down completion string, and out the perforations or fracturing sleeves, into the existing perforations for the purpose of re-fracturing the formation, **Figure 2**.

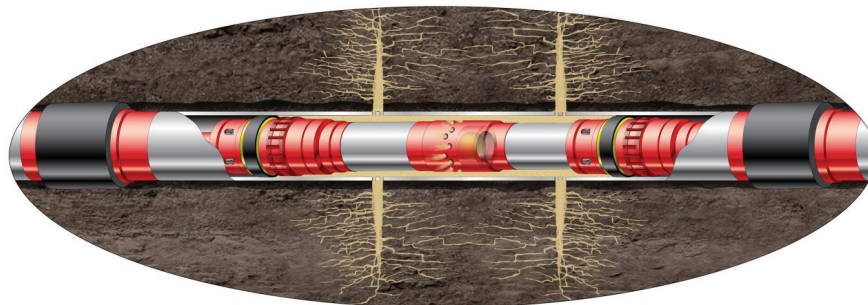


Figure 2. Example of new completion string installed inside existing wellbore.

A sixth potential method for re-fracturing exists wherein a set of casing patches is run into the wellbore to isolate each set of perforations. The wellbore can then be re-perforated and fractured using a variety of completion methods.

The retrievable fracturing sleeve and chemical diversion packer system outlined in this paper presents yet another viable alternative for re-fracturing operations. It combines using chemical diversion techniques with a retrievable service string consisting of ball-drop activated fracturing sleeves and a retrievable service packer. This enables the re-fracturing treatment to be continuously pumped by dropping balls from surface to activate each fracturing sleeve thereby providing increased operational efficiency. Each re-fracture treatment is isolated in the annulus with the chemical diversion packer and directed out a set of perforations or already installed fracturing sleeve. Then, once the re-fracture treatment has been completed, the service string can be retrieved from the wellbore and redressed. This helps enable the string to be run into multiple wellbores for enhanced re-fracturing economics. Additionally, the fracturing sleeves in the retrievable service string can be spaced out along the entire length of the wellbore to provide more even distribution of the re-fracturing treatment.

Technology Discussion

To perform the re-stimulation treatment, the retrievable string must provide the following capabilities:

- Efficiently place the individual treatments along the wellbore.
- Provide string anchoring capability.
- Withstand tubing movement attributed to pressure and temperature variations.
- Create a pressure barrier between the lateral length of the well to be treated and the upper annulus.
- Allow fluids diversion and selective access to the pre-perforated wellbore.
- Allow easy string retrieval after re-stimulation operation.
- Provide a temporary isolation barrier between designed fracturing stages.

Based on these requirements, the retrievable fracturing sleeve and chemical diversion packer completion consists of three primary components, which enable its functioning. These components are the retrievable service packer, which provides both annular isolation of part of the wellbore and anchoring of the retrievable service string during re-fracturing operations, ball-drop activated fracturing sleeves, which provide access to previous existing perforations or fracturing sleeves for re-fracturing, and the chemical diversion packer, which is pumped into the annulus and then gels, building compressive strength to provide annular isolation and diversion of fracturing stages.

Retrievable Ball-Drop Fracturing Sleeve (RBDFS)

The retrievable ball-drop fracturing sleeve (RBDFS) is the primary component of the re-fracturing service string and is intended to provide selective communication between the re-fracturing string and the wellbore. The RBDFS builds on standard fracturing sleeve design with some key features to help enable the RBDFS to be easily redressed and reused. The RBDFS consists of five primary parts—top sub, bottom sub, ported case, inner sleeve, and ball seat. **Figure 3** shows a RBDFS.

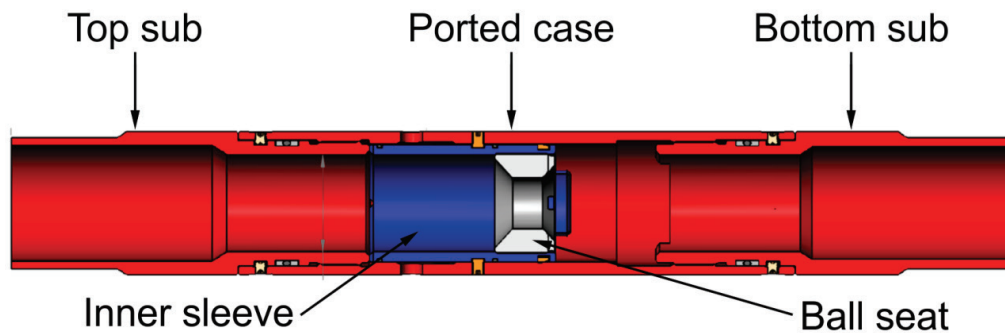


Figure 3. Retrievable ball-drop fracturing sleeve.

The top and bottom subs connect the RBDFS to the tubing and can be made with a variety of different threads. The subs are threaded and connected to the ported case of the RBDFS. Set screws, placed at the connections between the top and bottom subs and the ported case, assist with holding the connections together during stimulation operations, removing the need for the extreme torque, which is typically applied to the assemblies intended for permanent completions. This feature makes the RBDFS easier to redress for multiple re-fracturing operations. The ported case contains threaded exit ports through which the stimulation fluid is injected. If desired, the operator can adjust the total exit ports flow area by installing specialized exit port inserts. Inside the RBDFS is the inner sleeve, which is shear-pinned in place. This inner sleeve isolates the exit ports in the ported case until the sleeve is opened. The shear pins immobilize the inner sleeve of the RBDFS until enough pressure is applied to open the RBDFS during stimulation operations. Pressure value to open the sleeves can be adjusted by modifying the number of shear pins installed. Finally, the ball seat is threaded into the inner sleeve of the RBDFS. The ball seats come in graduated sizes to provide multiple zones that can be stimulated through the re-fracturing service tool string. The number of available zones depends on the outer diameter (OD) and inner diameter (ID) size of the RBDFS, and any other restrictions in the retrievable re-fracturing service string or surface equipment; Canning et al. (2013).

Retrievable Service Packer (RSP) Design

The retrievable service packer (RSP) is used primarily as an anchoring mechanism to hang the retrievable re-fracturing service string and withstand the tubing movement caused by pressure and temperature changes during re-fracturing pumping operations. The RSP also provides a seal between the upper annulus and the portion of the well to be re-stimulated, **Figure 4**.

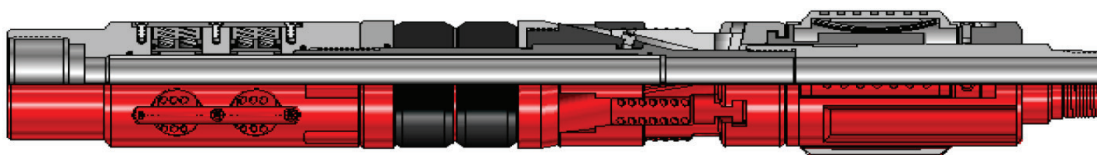


Figure 4. Example of a retrievable service packer.

The RSP typically includes a J-slot mechanism, mechanical slips, packer elements, and hydraulic slips. Large, heavy-duty slips in the hydraulic hold-down mechanism help prevent the tool from being pumped up the hole. Drag blocks in the lower section of the RSP provide the friction between the packer and the casing wall to operate the J-slot mechanism during setting and un-setting of the RSP. Typically, the RSP selected has a large full bore ID to help reduce pumping friction created during the re-fracturing treatment. Another key feature for selection of the RSP is to help ensure that it can also be easily redressed to be used for multiple re-fracturing operations.

Chemical Diversion Packer (CDP)

While pumping the treatment fluids through the RBDFS, a diversion mechanism must be in place to focus treatment energy and fluids into the intended set of existing or new perforations, fracturing sleeve ports, or other types of entry points created or installed as part of the primary completion. As a result, a chemical diversion packer (CDP) is used to both divert the re-fracturing treatment and also provide annular isolation between target re-fracturing stages.

The CDP is a long-life viscous gel that resists flow because of its high viscosity. Mainly composed of a cross-linker and a blend of buffering and gelling agents, it provides a temporary divergence capability by forming a barrier downhole that prevents treatment fluids from migrating to non-targeted sets of perforations or fracturing sleeve ports. The gelation process occurs at downhole temperatures; so, it is easy to mix on the surface with any kind of mechanical agitator device, turbine blender, etc. When it is no longer necessary, the CDP is easily removed with hydrochloric acid (HCl) or by providing enough time for the CDP to degrade.

Attention should be paid to the well temperature and completion fluid pH when displacing the CDP downhole. Higher wellbore temperatures can increase the rate at which the CDP will solidify. In most cases, it is necessary to cool the well down by circulation before displacing the CDP downhole. With this kind of fluid, it is necessary to perform tests to define the actual set and degradation time under actual wellbore conditions.

Retrievable Re-Fracturing System Operation and Installation

The retrievable re-fracturing service string system (RRFS) can be run in a variety of unconventional or mature wells, which require re-fracturing or re-stimulation. The target wellbore could have been completed by any number of primary completion methods, such as the traditional plug-and-perforate method, ball-drop fracturing sleeve systems, CT fracturing methods, or CT activated fracturing sleeve systems. If desired, additional perforation sets can be created before running the RRFS. This can facilitate the stimulation of new sections along the target pay zone.

As previously discussed, the RRFS consists of a RSP, RBDFS, and CDP. This RSP is then connected to the RBDFS, which are spaced out using tubing joints. The RBDFS are spaced out such that, when the RRFS reaches the target depth in the wellbore, the RBDFS are positioned adjacent to the existing or new perforations, fracturing sleeve ports, or other types of entry points previously installed or used as part of the primary completion string. The RRFS is then run into the wellbore on tubing to the target measured depth. Once on depth, and when the RBDFS have been successfully spaced out, the CDP is pumped down the tubing and out into the annulus. The RSP is then set, usually by rotation of the tubing, to achieve anchoring and annular isolation. The CDP is then given time to solidify before the re-fracturing operation commences.

Once the CDP gels and solidifies, the re-fracturing operation can commence. Pumping begins, and a fracture ball is released into the stimulation fluid stream on surface. The fracture ball then travels down the tubing until it reaches the target RBDFS. Increased pressure opens the target RBDFS, and the fracture ball then diverts the fluid flow through exit ports in the RBDFS. The re-fracturing treatment is then directed to the entry points to the formation adjacent to the RBDFS and isolated from other stages in the annulus by the CDP, **Figure 5**. The fracture ball dropping process is then repeated multiple times until the entire re-fracturing operation has been completed.

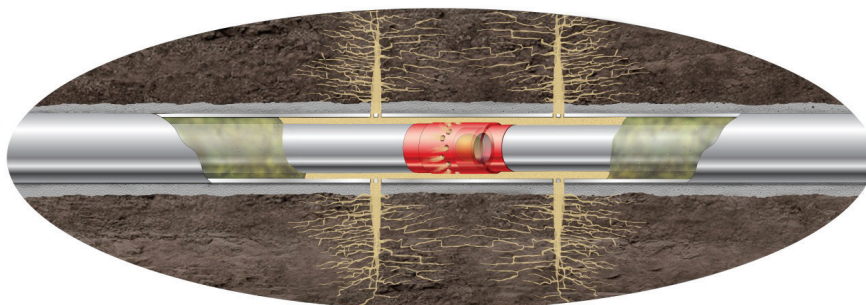


Figure 5. Example RRFS during Re-Fracturing Operations.

After re-fracturing, the CDP is given time to degrade. The time necessary to degrade is based on wellbore conditions and is verified by laboratory testing before commencing the re-fracturing operation. Once the CDP degrades, tension is applied to the string to unset the RSP. The RRFS can then be retrieved from the wellbore and redressed to be run in additional wellbores.

Case Histories

RRFS type systems have been used to stimulate wellbores since the early 2000s. Early RRFS systems contained RBDFS that were suited for the stimulation treatment requirements of conventional and mature wellbores of the time. One of the first case histories of a RRFS, was for primary stimulation of four wells in the San Andreas formation in two different fields in the Permian Basin. Each of the four wellbores contained openhole lateral sections which were drilled from previously existing vertical wellbores. The RRFS was selected as the completion method for a variety of

reasons including; poor completion economics of running a cement liner, questions about the mechanical integrity of the existing vertical wellbore, and the need for multiple stages of stimulation to be performed while being isolated from one another. Each well had a MD of around 4,900 ft with lateral lengths ranging between 1,800 and 2,450 ft. The RRFS system used was able to stimulate seven individual stages in each wellbore. The wells were treated using a combination of a gelled acid system and a heated acid system at a pump rate of up to 10 BPM and with up to 6,000 gallons of acid to maintain target contact time with the formation. Each job was executed successfully and resulted in increased production versus the actual production from just the original vertical wellbore. The case history also noted that the use of the RRFS reduced the required hydraulic horsepower for the stimulation job and lowered the cost of the completion; Beebe et. al. (2005).

In 2007, an additional case history was published illustrating the use of RRFS in the Permian Basin for re-stimulation of existing wellbores. The six openhole horizontal wellbores were in the San Andreas formation in Dawson and Gaines County in Texas and once again hydraulically fractured with the RRFS. Each wellbore had been previously perforated and stimulated but then a sidetrack was drilled from the existing vertical wellbore. These next set of wellbores had longer lateral sections with more stages to be fractured than the previous case history. Lateral lengths ranged from 2,212 ft to 4,102 ft and each well was stimulated with 11 stages using the RRFS (see example wellbore schematic **Figure 6**). Additionally, bottom hole pressure gauges were deployed as part of the RRFS completion string to validate the CDP was providing stage isolation during each stimulation treatment. In each wellbore, the RRFS was deployed successfully and the CDP placed in the openhole annulus. During stimulation, pressure was monitored for each fracturing treatment and with the use of memory bottom hole gauges. In each wellbore, 11 stages were successfully stimulated using the RRFS. After stimulation, pressure data from the stimulation job was compared to pressure data from the memory gauges. For the majority of fracturing stages, once stimulation began only a slight pressure increase of 200 to 400 psi was seen on the memory gauge as compared to the static state pressure reading. The authors concluded that this was the CDP being compressed during fracturing; however, since the pressure increase was not more severe, the CDP provided good isolation of each fracturing stage. Production results from this case history showed similarly positive results increasing the average production from the wellbores. Again the authors noted that the hydraulic horsepower requirements were reduced by using the RRFS also lowering the completion costs; Laney et. al (2007).

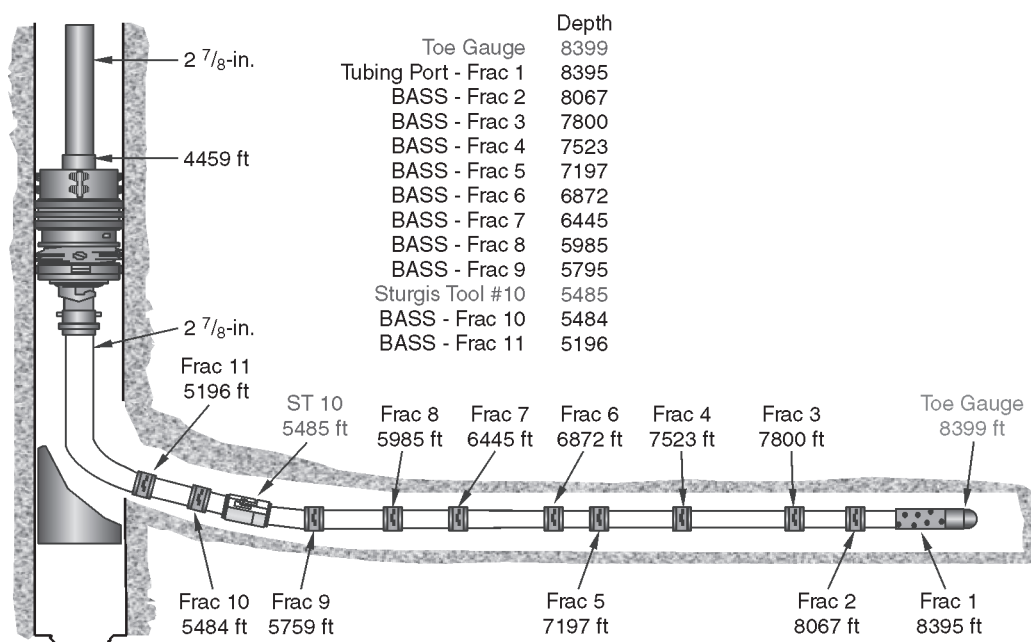


Figure 6. RRFS deployed in wellbore (Laney et. al. 2007).

In a more recent field example, a RRFS system was deployed in a wellbore in the Mid-Continent region of the United States to re-stimulate 11 stages in an existing wellbore. The wellbore was drilled to a TMD of almost 10,500 ft with a TVD near 8,700 ft. A long string of 5-1/2 in. casing was then set in the wellbore and 11 intervals were perforated for primary stimulation. Due to production decline, the well became a candidate for re-fracturing and the RRFS was selected to enable the re-fracturing treatment. The RBDFS were spaced out in the RRFS such that they would be adjacent to the existing perforations during re-stimulation. The system was then successfully run and set in the wellbore. The re-fracturing design consisted of 11,000 gallons of 15% Hydrochloric Acid, approximately 375,000 gallons of treated water, over 550,000 gallons of treated water carrying over 350,000 lbs of proppant, and 10,000 gallons of gelled treated water. The re-fracturing treatment was pumped at an average rate of 25 BPM and each stage was completed as per design. The RRFS was then successfully removed from the wellbore and the well was brought onto production.

RRFS Evolution

Early versions of the RRFS system experienced significant wear on the RBDFS used to provide access to the formation for stimulation. As a result, the early RBDFS could only be redressed a few times before replacement of the tools was necessary. Despite this, the RRFS systems proved to be a cost effective method for the delivery of effective stimulation. As unconventional resource development began to increase, ball-drop fracturing sleeve technology began to evolve with the requirements of fracturing treatments used to produce these types of resources. Ball-drop fracturing sleeve designs improved to handle higher fracturing stage counts, faster pumping rates, increased proppant volumes, and greater proppant concentrations. Over time, ball-drop fracturing sleeve completion systems have become common in many prominent unconventional resource basins throughout

North America, primarily because of the improved efficiency they can provide (Frugé et al. (2013)) while also providing equivalent production results to plug-and-perf completions, Stegent et al. (2011). These improved BDFS design features were then incorporated into RBDFS for RRFS application. This has enhanced the RRFS for re-fracturing of modern unconventional wellbores and also provided more possible fracturing stages for re-fracturing longer sections of target wellbores. To date as illustrated, most field applications have been in older unconventional wellbores with shorter lateral lengths and shallower true vertical depths (TVDs). However, RRFS have proven to be effective in these applications in placing proppant and acid fracture treatments for re-fracturing operations. RRFS have also been adapted for offshore applications to enable re-stimulation., Canning et al. (2013).

Conclusions

Because the RRFS can be spaced out along an entire lateral section and it can be retrieved from a wellbore, it can have several potential positive impacts on re-fracturing operations of unconventional wellbores. First, the process can be repeated in several wellbores while only re-dressing the RRFS, thereby improving re-fracturing operational economics. Second, as the RRFS can be spaced along the longer sections of the target pay zone, the RRFS can reach farther into a wellbore. Therefore the potential exists that more of the target wellbore can be re-fractured compared to chemical diversion techniques, or the RRFS could be used to complement chemical diversion techniques and re-fracture portions of the wellbore that could not be re-stimulated using chemical diversion. This can provide access to additional portions of the target interval in the wellbore. However, because the RRFS is run inside an existing wellbore, which limits the RBDFS size, the number of available stages can be limited to less than the number of stages used in the original completion. This could necessitate the evaluation of the reservoir such that the most optimal portions of the wellbore can be targeted for re-fracturing or combining the RRFS with chemical diversion techniques to enable total wellbore coverage in unconventional wells with high stage counts. Also, careful attention must be applied to the CDP design such that it does not gel too quickly during installation and also to help ensure it degrades under wellbore conditions. This is often performed through laboratory testing before each application. However through memory pressure gauge data analysis, the CDP has proven to provide positive annular isolation. In addition, because most applications to date have been in shorter laterals and shallower unconventional wells, evaluation is still necessary for using RRFS in newer unconventional wellbores containing longer lateral sections, increased stage counts, or deeper TVDs. This will help define the most effective ways to use this type of technology for re-fracturing applications in unconventional wells with more recent wellbore construction parameters. Overall the RRFS has proven to be a viable solution for re-fracturing operations of unconventional wellbores, can lower hydraulic horsepower requirements, enhance stimulation efficiency, and improve completion economics.

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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.



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