Multi-stage fracturing completion technologies and methods have become increasingly sophisticated as the techniques evolve to meet the demands of the ever-expanding number of unconventional reservoirs being discovered today. Unconventional reservoirs often rely on horizontal wellbores drilled through the target section of the formation, which are then stimulated dozens of times along the length of the lateral. In the early days of the unconventional resource revolution, the traditional plug and perforate completion method used in vertical wells was adapted to meet the requirements of conveying completion tools successfully to depth in a horizontal wellbore. As the number of target stages requiring stimulation along the lateral section continued to increase, operators sought more efficient methods for completing the wells requiring multi-stage fracturing. This gave rise over a decade ago to multi-stage fracturing sleeve technologies activated by releasing a ball at surface into the wellbore to activate the target-fracturing sleeve.

Ben Wellhoefer, Halliburton, USA, reviews the increasingly sophisticated technology behind the cementing of multi-stage fracturing sleeves.
technologies had to change in order to meet these new requirements and continue to be efficient, viable completion options. As a result, multi-stage fracturing sleeves have been improved to help provide the flexibility needed for each unconventional reservoir along with becoming adaptable to new fracturing techniques. Today’s multi-stage fracturing sleeve systems can provide over 50 potential fracturing stages with single or multiple entry points per stage. They can be run in extended reach wellbores on a production liner or long string of casing and with multiple different methods of annular fracturing stage isolation. In fact, the number of operators who use cement as their chosen method of annular fracturing stage isolation with multi-stage fracturing systems has begun to increase. Cemented fracturing sleeve systems have shown that they provide equivalent production in some unconventional resources plays (Stegent, et al. SPE 148642), provide flexibility of design (Ferguson, et al. SPE 158490) and increase completion efficiency (Adcock, et al. SPE 163542).

Early fracturing sleeves systems improved efficiency, but were limited on the number of available stages. As operators continued to drill longer laterals, decrease fracturing stage spacing and increase the number of fracturing stages per wellbore, multi-stage fracturing sleeve technologies had to change in order to meet these new requirements and continue to be efficient, viable completion options. As a result, multi-stage fracturing sleeves have been improved to help provide the flexibility needed for each unconventional reservoir along with becoming adaptable to new fracturing techniques. Today’s multi-stage fracturing sleeve systems can provide over 50 potential fracturing stages with single or multiple entry points per stage. They can be run in extended reach wellbores on a production liner or long string of casing and with multiple different methods of annular fracturing stage isolation. In fact, the number of operators who use cement as their chosen method of annular fracturing stage isolation with multi-stage fracturing systems has begun to increase. Cemented fracturing sleeve systems have shown that they provide equivalent production in some unconventional resources plays (Stegent, et al. SPE 148642), provide flexibility of design (Ferguson, et al. SPE 158490) and increase completion efficiency (Adcock, et al. SPE 163542).

However, the cementing of multi-stage fracturing sleeves can present unique challenges in unconventional reservoir wellbores as opposed to its openhole isolation counterparts. Some of the key factors behind successfully cementing multi-stage fracturing sleeve systems and ensure they are a viable completion method option include: fracturing sleeve design, effective wiping of the completion casing string, cement blend and properties and the procedures followed while cementing of the production completion string containing the multi-stage fracturing sleeves.

**Fracturing sleeve design**

Most often, multi-stage fracturing sleeves are run as an integral part of the production casing string on either a liner hanger or long string. The multi-stage fracturing sleeves are typically activated by pressure from the surface, a surface ball drop process, or by mechanical means through wellbore intervention. While cementing the completion string into the wellbore, both the ID and the OD of the multi-stage fracturing sleeve will be exposed to the cement slurry. Therefore, any debris or cement left in the ID of the completion string could affect the ability for the multi-stage fracturing sleeves to operate during the stimulation of the wellbore. Conversely, multi-stage fracturing sleeves contain exit ports in the sleeve, which provide access to the formation once the sleeve has been opened during the fracturing treatment. Once again, should these ports become plugged, they may inhibit the operation of the fracturing sleeve or create other issues during wellbore stimulation. As a result, the actual design of the multi-stage fracturing sleeve becomes tremendously important in whether or not it will be successfully cemented into the wellbore. First, the multi-stage fracturing sleeve should be designed in a way, which allows the cement to be wiped from its ID during the cementing process. This typically means eliminating sharp angles in the sleeve to allow it to be easily wiped clean by the wiper dart and minimising areas in the sleeve with a decreased ID where cement could collect and not be wiped free.

Second, the multi-stage fracturing sleeve should include features that help keep the cement and other wellbore debris out of the exit ports while running the completion string and cementing the wellbore. This can be accomplished by inserting degradable debris barriers into the exit ports in the multi-stage fracturing sleeves.

Lastly, an ideal cementable multi-stage fracturing sleeve design should allow for enough force to be generated during the opening process, so that it can overcome the cement or debris deposited either in the exit ports or the ID of the tool, should the unplanned deposition of debris or cement take place in the sleeve.

**Cement wiping efficiency**

As noted above, another important factor in cementing multi-stage fracturing sleeves systems in an unconventional wellbore is the ability to wipe the completion string clean of the cement slurry. Since these sleeves operate most often by a surface ball-drop procedure, pressure, or mechanical means, if cement is not effectively wiped from the completion casing string, it can hinder the operation of the fracturing sleeves. Any residual cement could prevent the activation balls dropped from the surface from reaching their targeted fracturing sleeves, could prevent pressure from being transmitted to any pressure-activated fracturing sleeves, or hinder being able to
intervene and mechanically shift any tools activated by mechanical means.

This typically means that the wiper dart technology used should be fit-for-purpose and provide maximum effectiveness. In the case of pressure or mechanically operated multi-stage fracturing sleeves, which do not contain a ball seat restriction, standard high wiping efficiency plugs can be used as there is little or no restriction in the ID.

In the case of ball-drop activated sleeves, the fracturing sleeve contains a ball seat, which is only activated by a ball dropped from the surface during stimulation. This ball seat forms a restriction, and special wiper dart technology is required to wipe the completion string. These specialised wiper darts must have the ability to pass successfully through the ball seat restrictions in the fracturing sleeves and still efficiently wipe the completion string ID clear of the cement slurry. This often requires the wiper darts used in cemented multi-stage fracturing sleeve completions to be much more flexible and much longer than standard wiper plug sets. This helps ensure that the energised wiper fins are in contact with the completion string ID on both sides of the ball seats as they pass through the restriction and wipe the ID of the multi-stage fracturing sleeves. It is important to note that in a cemented multi-stage fracturing sleeve system, fewer fracturing stages are typically available, since using wiper darts precludes the use of certain ball seat sizes based on the specialised wiper dart dimensions.

**Cement slurry design**

A third key to successfully cementing multi-stage fracturing sleeves is the cement slurry used. The cement slurry should provide effective annular isolation of the individual fracturing stages and be able to be effectively removed from the completion string ID by the wiper dart technologies available. Through experience in cementing unconventional reservoirs, it has been discovered that the cement blend should exhibit three key properties, no matter what type of cement is selected. These include a stable cement blend containing little to no free water, a high viscosity and low compressive strength. A stable cement blend helps ensure that the cement will set up properly and reduce the risk of mud-channels or micro-annuli forming. Higher viscosity means that it is easier to place the cement in the wellbore and helps ensure that effective isolation is achieved in the areas where it is needed. Lastly, using a cement blend with lower compressive strength reduces some of the challenges that may be encountered when stimulating wells that were completed with multi-stage fracturing sleeves. Some cement blends, such as acid-soluble cements, provide all the benefits illustrated above and have the added benefit of being able to be partially removed with the application of acid. This can further reduce potential challenges during fracturing of the wellbore.

**Cementing operations**

Finally, it should come as no surprise that the procedures used to cement multi-stage fracturing sleeves in a wellbore must differ from those of running openhole sleeve systems, as well as be specifically tailored for the completion application. It is worthwhile to look at a few of the most important factors. First, the surface hook-up of the cementing equipment is critically important. The surface iron should be hooked up so that a cement line can be washed up to an open top tank or the pit. This minimises the risk of residual cement in the lines being pumped down hole after the job has been completed. Next, any shut downs should be minimised to prevent cement from free falling. Additionally, the wiper darts should be displaced at a fairly high rate to keep the wiper dart engaged with the cement slurry and the entire fluid system, including the dart, moving together throughout the cement job. It can also be advantageous to allow for additional joints of casing at the toe of the wellbore so debris can collect and be brought along behind the wiper dart. This helps ensure that the debris will not hinder operations by collecting in the extra space of the shoe track. Finally, special displacement fluids can be required in cemented multi-stage fracturing sleeve applications. These fluids often further mitigate the risk of any residual cement inhibiting fracturing sleeve operations during stimulation of the wellbore.

**Viable option or risky business?**

As operators increasingly continue to push toward cement as the preferred annular isolation method in unconventional reservoirs, multi-stage fracturing sleeve systems should be designed to accommodate this trend toward cemented completion systems. This ensures that operators have the flexibility in completion options needed to help optimise wellbore production, lower their cost per barrel of oil equivalent, and provide a maximised return on investment for their unconventional reservoir assets. However, as seen in this article, this is not a simple task. Attention must be paid to the multi-stage fracturing sleeve design, wiper dart technology employed, cement blends being used, and also the procedures for cementing completion strings containing multi-stage fracturing sleeves in an unconventional formation wellbore. By utilising some best practices and procedures developed over the decades of service since the introduction of multi-stage fracturing sleeve technologies, challenges to cementing these sleeves can be overcome. Operators can now select the best completion option to meet the demands of today’s oilfield and the unconventional resource revolution.