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# Application of Ball-Drop Technology to Improve Efficiency and Stimulation of Limited Entry Completion Systems

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## Abstract

Ball-drop or ball-activated completion systems for multistage hydraulic fracturing are designed to reduce stimulation time and improve efficiency by being pumped in one continuous operation. Actuation balls are used in these systems to activate sliding sleeves and internally isolate the production liner into individually isolated stages. While this technology is traditionally associated with single point entry stimulation (one ball per sleeve), advancements in ball-drop technology have led to the development of a system that uses one ball to activate multiple sleeves, combining the efficiency of ball-drop completions with the placement accuracy of limited entry stimulation in cemented liner completions.

Limited entry ball-activated completion technology has evolved over time. Each iteration has been designed with fewer components to further improve the operational efficiency of having one ball activate multiple sleeves in a treatment zone. The latest advancement in this technology has seen a 40% reduction in the number of components, which in turn reduces operational risk. While limited entry ball-drop completion systems have been run for over a decade in openhole applications, the newest version was specially designed to run in a cemented liner application.

The latest version of limited entry ball-activated completion systems is designed to stimulate a high number of entry points in one treatment more effectively, reduce overdisplacement, reduce completion time, remove risk of wireline and coiled tubing runs, eliminate the need to millout the system prior to flowback, and solve entry point erosion concerns. Each port or sleeve is designed to have its own back pressure or limited entry effect (equivalent perforation pressure), which is customizable for each application. By using a non-erodible material in each sleeve the limited entry effect is designed to be consistent throughout the entire stimulation. This is a significant improvement over existing limited entry tools and plug-and-perf completion designs and will lead to more effective distribution throughout the entire stimulation.

In each field trial to date using the new limited entry ball-drop completion technology, all the sleeves have opened and stimulation treatments have been delivered as designed. In the cemented liner applications, the limited entry ball-activated sleeve system allowed stage to stage transitions without shutting down pumping operations.

Limited entry ball-drop completion systems provide instant time and operational improvements to traditional cemented liner completion methods. These time and cost improvements can significantly reduce

## Introduction

Oil and gas operators have been successful in boosting production from horizontal wells in unconventional reservoirs over the last decade. Part of this increase can be attributed to advances in several areas of directional drilling and multistage completion techniques that have allowed for increased lateral lengths and tighter stage spacing. Changes in completion design during this time have also trended towards increased pump rates, and higher fluid and proppant volumes.

In cemented liner completions, the most common method used is plug-and-perf. This completion technique is mature and proven, having been applied in thousands of wells around the world. Most horizontal plug-and-perf completions performed today group a number of perforation intervals, or clusters, into the same stage. The limited entry (LE) stimulation technique is then used to simultaneously stimulate all perforation clusters. The goal of the limited entry technique is to create a pressure drop across the perforations that will help uniformly distribute fluid to each perforation cluster by combining increased rate and reduced number of total perforations. However, even or effective distribution still remains one of the technical challenges of stimulating horizontal wellbores.

Despite the simplicity and popularity of plug-and-perf completion operations, producers are faced with a few legacy challenges, as well as more recent challenges due to the advances that have led to longer and deeper horizontal wells. A few of these challenges in plug-and-perf completions include:

- Poor perf cluster efficiency and unproductive clusters
- Excess fluid volumes and overdisplacement
- Completion time
- Operational risk
- Millout issues

**Unproductive Clusters**

Studies have shown that, on average, the majority of a well's production comes from only 20-30% of perforation clusters (Lecampion 2016). Another recent study concluded that the inefficiencies found from LE plug-and-perf completions are due to perforation clusters becoming inefficient as the job progresses. This is due to erosion of perforations as proppant and fluid are pumped, and thus the change in the LE design. The study also concluded that increasing the number of perforation clusters in a stage does not typically increase the number of productive clusters (Ugueto C 2016). Both of these studies show the need for a proper and consistent limited entry design is needed for effective distribution and that ineffective distribution does lead to a reduction in ultimate recovery from the reservoir.

If a perf cluster is under stimulated, or not completed as intended, it is likely to perform poorly and the ultimate recovery will be less than expected. In addition, if one cluster is under stimulated, then other clusters will receive more fluid and proppant than expected causing overstimulation of the other clusters. In some field development this could lead to interwellbore communication or cause the fractures to interact with nearby wells. Ultimately, when a LE design is not performed as planned the amount of stimulated reservoir volume (SRV) is less than expected and valuable reserves are left in the reservoir.

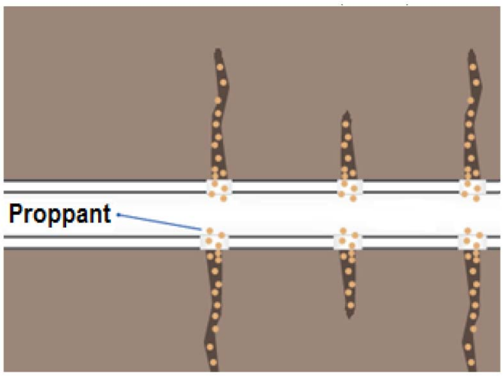


**Figure 1—Ineffective Limited Entry design can lead to understimulated perforation clusters or sleeves and ultimately less production.**

Tracer diagnostics also validate the premise that the initial (heel-most) perforations in a cluster can quickly erode due to the high velocity flow of proppant slurry (Phelan 2013). As these perforations enlarge, other clusters within the stage are not effectively stimulated, correlating to subsequently poor production.

## Fluid Volume and Overdisplacement

Plug-and-perf practices require the wellbore to be flushed clean between each stimulation treatment. The flush is done to ensure there are no issues when pumping the perforation charges and bridge plugs down the wellbore to prepare the next stage. The operation of flushing the wellbore clean and pumping the plug and perforation guns down to the next stage could consist of several hundred barrels of fluid behind the final sand stage (Phelan, Casero 2013). Not only does this process require more fluid than sliding sleeve systems, it also overdisplaces the fracture treatment for each interval and can contribute to a loss in near wellbore conductivity.

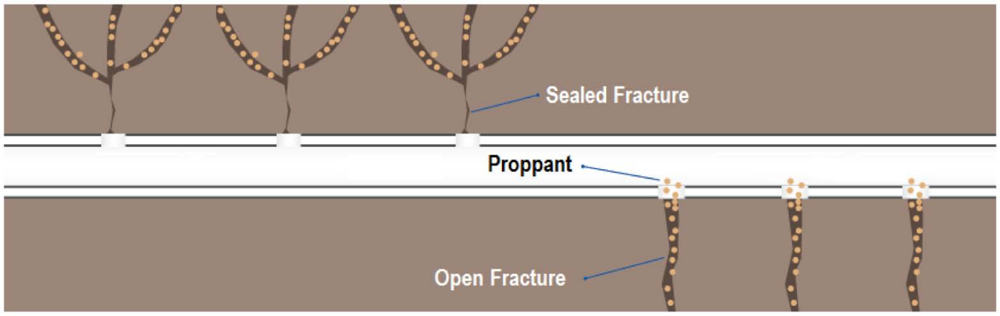


**Figure 2—Overdisplacement of proppant can allow a fracture to close and lose near wellbore conductivity.**

## Completion Time

While plug-and-perf completions are known for being flexible and simple, it is an inherently inefficient procedure, requiring multiple trips in and out of the well for each stage to detonate perforation charges, set bridge plugs and mill out conventional bridge plugs. Operational improvements such as zipper stimulations and technology improvements to bridge plugs have allowed for a reduction in downtime, but still remain inefficient. Completion downtime costs in US unconventional plays between two wells treated identically can cost the operator hundreds of thousands of dollars.

## Operational Risk

Tripping in and out of the wellbore adds to non-productive time, and increases the likelihood of encountering prematurely sets at an unplanned depth. In these situations, operators may choose to mill out or abandon the stage.

A recent analysis of completion effectiveness using the plug-and-perf limited entry technique using Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) has shown that greater than 70% stages experienced inter-stage communication. This was attributed to leaking plugs (Wheaton 2016). This study also showed that greater than 70% of a stage's fluid volume and proppant were placed in two perforation clusters or less and that in 64% of the stages one or more clusters took less than one quarter of the planned proppant of the stage.

Another operational challenge of conventional plug-and-perf is stimulating the toe or first stage of the wellbore. Unless the toe stage uses a hydraulically opened tool, coiled tubing is used to convey the perforating charges for the first stage. In these cases, friction in long laterals makes it difficult to push the bottomhole assembly to sufficient depth to begin treatment. The toe stimulation is critical in that lower stages are effectively lost if the bottomhole assembly cannot reach the toe of the well. Wireline tractors can be used to assist the bottomhole assembly, but this also adds cost and risk to the operation.

Other operational challenges encountered less frequently, but should still be noted are when perforation guns do not fire correctly. If flow through bridge plugs are run a wireline perforation rerun can be taken, however if a solid bridge plug was used a tubing conveyed perforation (TCP) run would be required. Another operational challenge in some horizontal applications is where operators are forced to drill laterals in extreme updip formations, greater than 100° inclination. Pumping plugs and perforation guns to depth can be an even greater challenge in updip formations that exceed the operating limits of setting the plugs and perforating the guns safely. Milling the bridge plugs out afterwards can also be an issue.

Finally, the safety and logistics of handling perforation guns and equipment must be considered in the completion design. This becomes a greater concern when perforation guns do not fire correctly. In some regions internationally it is more difficult to work with explosives than in the US plays where they are readily available and permits are easier to acquire.

### Millout Issues

Coiled tubing operations are required to mill out plugs at the end of traditional plug-and-perf completions, as well as every time a plug unintentionally pre-sets. Just as plug conveyance may be difficult in extended reach laterals, plug removal is also a major operational challenge and financial consideration. As longer laterals are drilled, milling out with coiled tubing can become a challenge due to limitations of weight on bit while milling, and the length of coiled tubing with respect to the total depth it can reach.

Milling out bridge plugs is particularly an issue in wells with low reservoir pressure. Low reservoir pressure can create challenges with circulation resulting in low annular velocity, which creates difficulties in flowing plug parts back to surface and increases the risk of stuck coiled tubing (Aviles 2015). Millouts provide a high variable cost at the end of the well.

## Limited Entry Ball-Activated Completions

Despite the challenges with plug-and-perf completions, it remains a common industry practice. As with the combined synergy of horizontal drilling and hydraulic fracturing to access previously uneconomic unconventional reservoirs, combining the effectiveness and efficiency of ball-drop technology with a limited entry treatment for cemented liner completions provides a solution that:

- Reduces completion time, fluid volume and operational risk with a continuous pumping operation
- Reduces chance of overdisplacement, maintaining near wellbore conductivity
- Eliminates plug millout issues using degradable ball technology

- Reduces cluster inefficiency and erosion by stimulating all entry points in a treatment zone

Limited entry ball-drop completion systems were first developed shortly after single point entry openhole multistage (OHMS) ball-drop systems were introduced in the early 2000s. Early limited entry tool design included a cutter assembly and multiple shear-activated stimulation jets. The actuation ball would land in the cutter assembly and then travel along the treatment zone, cutting off kobes from each stimulation jet to provide access to the formation. The actuation ball in the cutter assembly provided stage isolation inside the liner, while hydro-mechanical packers were used for annular isolation to segment the treatment zone. This system was primarily used for matrix acid stimulation treatments (Seale 2006).

### Further Development

As limited entry ball-drop technology advanced, and the need for more stages increased, the cutter assembly was removed from the system and the jet nozzles were activated directly using an actuation ball pumped from surface. This system was originally designed for an openhole application and could be run in two configurations: multiple sleeves in between each packer, or one sleeve between each packer, creating multiple individual intervals or entry points within one stage pumped from surface. These tools were used for both acid and proppant stimulation treatments, and established the versatility of limited entry ball-activated completion technology. Over the years, these limited entry ball-drop completion systems were run more than 200 times in numerous unconventional reservoirs around the world.

The transition to the use of a single ball for actuation reduced the number of tools required for each stage by removing the operational risk of leaving a cutter assembly and kobes in the wellbore; however, it increased the number of components in each sliding sleeve. The increased number of components in each sleeve introduced a new challenge when designing a limited entry ball-drop system for cemented liners.

## Cemented Limited Entry Ball-Activated Completions

The newest version of limited entry ball-drop technology was designed specifically for deployment in cemented liner completions. Combined with port covers and a coating that prevents cement from adhering to the tools, the sliding sleeve in this system is a simplified mechanical assembly with approximately 40% fewer components than earlier limited entry ball-drop completion technology.

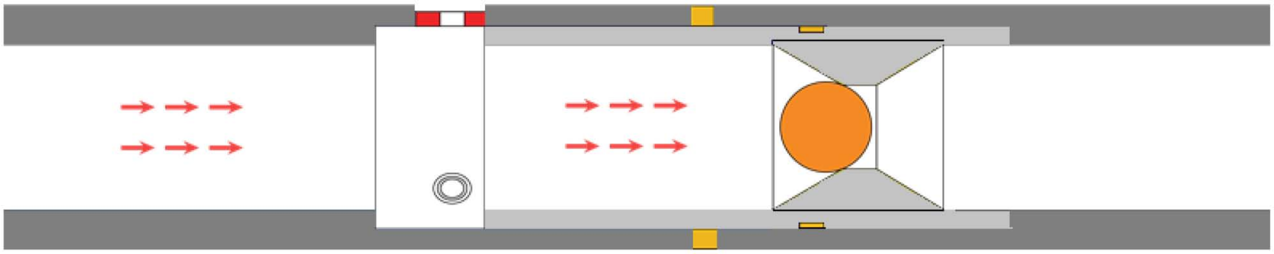

**Figure 3—Limited entry ball-activated sleeve designed with fewer components to reduce operational risk.**

The resulting cemented limited entry ball-drop completion system is designed to:

- Solve entry point erosion concerns by creating consistent diversion through the stimulation
- Effectively stimulate each entry point throughout the entire frac stage
- Stimulate a high number of entry points
- Reduce completion time and fluid volume pumped between stages

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