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SPECIAL ISSUE: Shale Gas, Subsea / Deepwater Technology

Stage multiplier technology takes multistage fracturing to the next level

Dan Themig, President, Packers Plus Energy Services, Canada

Ultra-high stage density is being implemented in most resource plays throughout North America. It appears that this trend will continue in the foreseeable future. With the search for high liquids as well as shortage of fracture equipment throughout North America and around the world, efficiencies are required to meet high stage count demand. The RepeaterPORT sleeve is a key technology going forward, with expectations that greater than 50 stages will be required to effectively drain tight rock in resource plays throughout the world.

When Packers Plus introduced the StackFRAC® HD™ (high density) system to the industry in 2009, it provided a step change in open hole, horizontal, multistage fracturing by providing an effective technology to allow for increased fracture stages from about 10 stages to 20 stages. Previous to this, the average stage count would typically range from 5 to 10 to stimulate a 1,200 m (4,000 ft) lateral. The remarkable thing about this introduction was the rapid acceptance and adaptation to higher stage numbers. Although the industry was uncertain as to the effectiveness of doubling stage count, it quickly found that the net result was an increase in IP (initial production). Over time it became apparent that higher stage numbers also resulted in a considerable increase in ultimate recovery.

The question was, if moving from 10 stages to 20 stages had such a dramatic effect on reserve recovery from a horizontal well, would continued increases in stage count have a similar result? And what is the crossover point for optimum stage count to economically complete wells using horizontal drilling and multistage fracturing?

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The optimum stage spacing is still being worked out for many of the major resource plays, but operators have quickly seen how higher stage numbers positively affect their recovery. Enhancements in modeling, together with experimentation in the field, soon showed that effective reserve recovery requires considerably more stages than even HD technology could achieve. In essence, through enhancements in modeling, decline curve analysis, and experimentation, it became evident that *the required stage count could be much higher, perhaps 40 or more in most resource plays*. Thus, ultra-high density fracturing stage counts are required to drain most of today's tight oil and gas resource plays. The question is, how can we achieve ultra-high density stage numbers in an efficient and cost-effective manner?

Attempting to increase stage count in cemented liners

As the industry continued to push for more stage capability, a part of this push was to utilize cemented liners

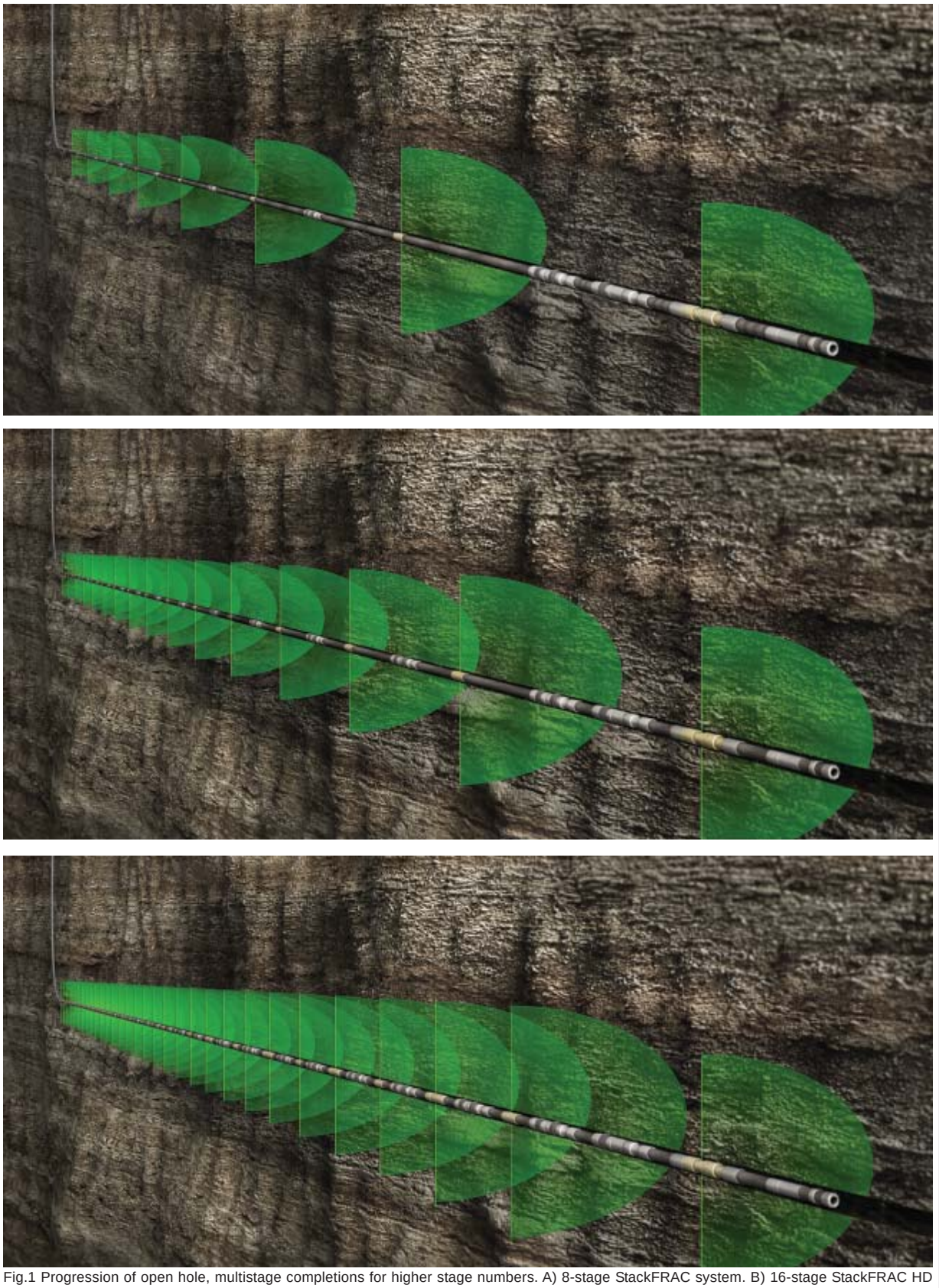


Fig.1 Progression of open hole, multistage completions for higher stage numbers. A) 8-stage StackFRAC system. B) 16-stage StackFRAC HD system. C) 30-stage StackFRAC HD system with RepeaterPORT sleeve technology.

with new limited entry perforating techniques to attempt to create more fracture density. Early thought was that a single perforation cluster would be the best option for draining horizontal reservoirs and numerous theoretical SPE papers were written about this. However, empirical evidence is probably a more important consideration, and as field experienced was gained it became clear that single perforation clusters were not the best method.

To add fracture stage density, operators began to increase to two and later three or four perforation clusters in an attempt to create simultaneous fractures utilizing limited entry. This proved beneficial from a production standpoint, albeit the results were not consistently significant. Some plays seemed to benefit, however, much debate continues as to whether the added perforation clusters are actually contributing to production. One study that evaluated the effectiveness of multiple perforation clusters proved somewhat disappointing (Baihly et al., 2010). A key finding in the paper was that, based upon production logging studies, only 30% of the intervals were actually contributing.

Multiple perforation clusters may appear to be a good way to increase fracture density, and decrease fracture spacing; however, the empirical evidence indicates that this simply is not effective. For a time, operators believed that if they pumped 6 stages with 3 limited entry perforation clusters, they would achieve close to 18 stages. However, based on the research, the more likely scenario is that rather than 18 fractures, the operator would end up with 6 effectively stimulated intervals. If this is the more likely scenario, then clearly it is not enough stages based upon the building body of empirical evidence.

In addition, it becomes logistically difficult, if not impossible, to provide adequate stage numbers using cemented liners and pump down bridge plugs. Due to the time-consuming nature of this technique, it reaches a practical limit for how many stages it can effectively create. Lastly, there are significant differences between production performance data using high stage numbers with cemented liners and high stage numbers with open hole, multistage fracturing systems (Snyder and Seale, 2010).

Hybrid intermediate steps

Once a high density approach (15 to 20 stages) was shown to be both economic and technically feasible, it was adopted and proved beneficial from a production enhancement standpoint. In certain plays, such as the Bakken, Granite Wash, Cardium, and Montney, among others, it quickly became clear that an even higher stage count was needed. In particular, the Bakken has seen a great increase in extended reach drilling by moving from standard length laterals of approximately 5,000 feet (1,500 m) to extended laterals of 10,000 feet (3,000 m) and further. With the open hole HD technology at maximum, hybrid approaches were developed in order to achieve an adequate fracture density to begin to close in on the optimum spacing between fracture treatments. This method combined StackFRAC HD with conventional "plug and perf" procedures to take stage counts to 30 and higher. The process utilized a graduated ball-drop system at the toe of the well to provide upwards of 20 stages. The remaining stages required that pump-down bridge plugs and perforating guns be utilized.

While the process is repeatable, it is extremely time-consuming and arduous to add a significant number of stages. In addition, problems such as bridge plug presetting are extremely expensive if coiled tubing drill out is required. A main disadvantage with this process is that significant proppant over displacement takes place while the bridge plugs are being pumped into place, in some cases requiring upwards of 700 barrels (>100 m^3) per stage. As this injection takes place it essentially pushes the proppant away from the wellbore for the previous stage or stages.

The good news with the hybrid systems, however, is that it proved beyond a doubt that ultra-high stage density had many benefits, the primary one being that it greatly increased ultimate recovery in tight resource plays, whether they be oil, gas, or gas with high liquids content. The problem with the hybrid approach was that at a time of expensive fracture equipment costs and a shortage of fracture crew days, it added significantly to both.

Increasing recovery without increasing costs – ultra-high stage count open hole systems

Utilizing conventional techniques of cemented liners with plug and perf methodology, the process actually reaches a point where it becomes a simple linear calculation. More stages means more time on location with fracture trucks, crews, supervision, and overhead. If performing six stages takes two days, then going to 24 stages or 30 stages may take up to a week. As with most developments, perfecting the same process will take you only so far and increasing operational efficiency will produce diminishing returns. Is it possible to significantly reduce the per stage cost for these high-density applications? The answer lies in technology.

The RepeaterPORT® sleeve represents the next step-change in

multistage fracturing. This breakthrough technology enables open hole systems to provide ultra-high stage density efficiently at a reasonable cost. The RepeaterPORT sleeve allows the same size ball to be dropped multiple times to precisely activate a specific port each time. Thus, additional fracture stages can be added without any down time between stages. The only additional time required to add a stage is the time required to pump the fluid and sand for that stage. The RepeaterPORT sleeve can now provide the ability to increase stage counts to 50+ stages with simple ball-drop pumping techniques. In this way, the RepeaterPORT sleeve builds on the success of stage increases found in StackFRAC HD that has effectively increased ultimate recovery in horizontal wells. Evidence is building, however, that there may be more to this story.

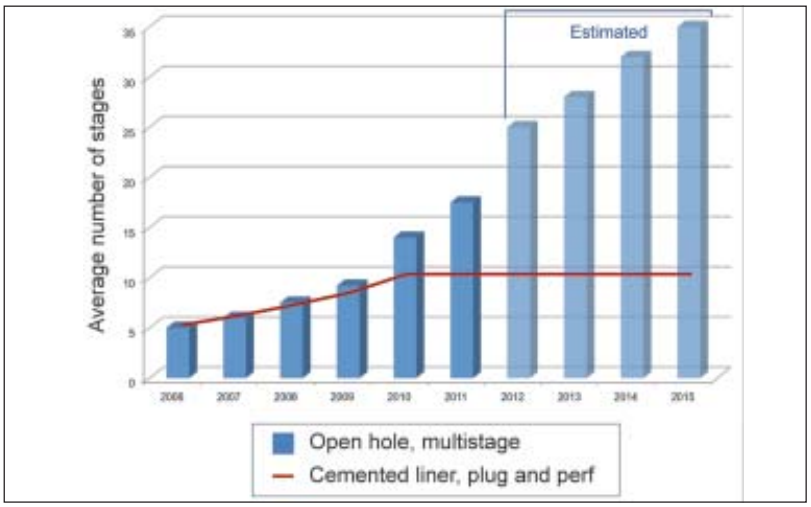


Fig.2 Average number of stages achieved over time with open hole, multistage systems and cemented liner, plug and perf technology.

The search for complexity

For many years, most of the fracture experts in our industry were quite adamant that multiple, long planar fractures were the best option to drain long horizontal wells. However, in recent years, the industry has begun to move away from planar fractures towards "fracture complexity." Complexity means that a less predictable and complex pathway is taken by the fracturing fluid, creating more near-wellbore contact area and less fracture extension. One of the factors that has caused this move is the limited capability to effectively carry proppant long distances with slick water. Even if you can create long fracture length with water, the benefits may be short lived due to the absence of proppant as you move further from the wellbore. Complex fractures may drain a smaller area, but the effectiveness of the drainage is increased considerably near wellbore, thus improving ultimate recovery. Complexity is also more easily achieved with open hole, multistage systems rather than cemented liners because microfracturing can take place along the horizontal.

Increasing liquids recovery

In a recent study performed by an operator working in the Cleveland Sand formation, it was found that ultra-high stage counts may in many reservoirs increase recovery of liquids and condensate in liquids rich gas plays. This study in a liquids rich gas area moved stage count from 8 to 15, then to 20+ stages. As the stage count increased, the liquids portion of production increased consistently and significantly (bbl liquid per MMCF gas). It is believed that this higher recovery of liquids due to increasing stage density is related to mobility of fluids in tight rock. Liquids have a lower mobility ratio through a the pore space in rock relative to gas, which has a lower molecular weight and moves more easily through rock. If the fracture density is increased, the liquids can move more easily to the wellbore.

Case history results

As mentioned, the Bakken formation has seen steadily increasing stage number requirements as longer laterals are drilled. Once the RepeaterPORT sleeve technology was available, it was implemented gradually and is now achieving 30+ stages on each horizontal well. For example, one operator used the new RepeaterPORT sleeve in conjunction with the field proven StackFRAC HD system to install and fracture 38 stages in the Bakken formation. The system was run into a wellbore with a lateral length of 9,760 ft (2,975 m) and a measured depth of 20,310 ft (6,190 m). A combination of 18 RepeaterPORT sleeves and 20 FracPORT™ sleeves were used with an average stage length of 270 ft (80 m) to increase communication with the formation. The success of the new RepeaterPORT sleeve in this well has encouraged this operator and others working in the Bakken to use the technology for additional 30+ stage wells.

In a recent series of wells in the Montney Shale gas formation in Canada, the operator had increased stage count – initially from about 8 to 15 stages using open hole multistage fracturing systems. By moving from 15 to 30 stages the production increased on average by

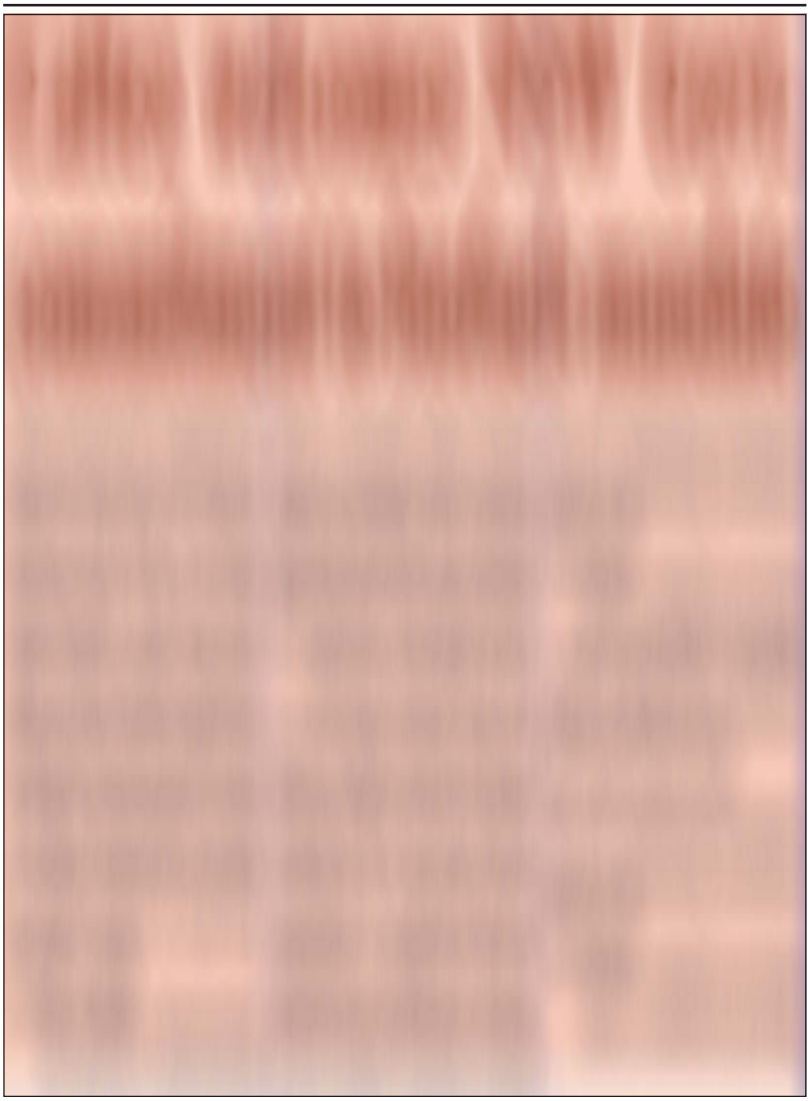
approximately 70% while not dramatically increasing the time required to perform stimulation treatments. In addition, higher liquids were seen on most wells (study not yet published). In addition, in an effort to optimize fracture treatment design, the operator has been able to reduce the stimulation volume required per stage by approximately half.

What we have learned

- Open hole completions outperform cemented liners
- Cemented liner "perf and plug" completions are not effective for ultra-high density treatments because they become time-consuming and costly
- Ultra-high stage count may allow reduction in water usage on a per stage basis
- The RepeaterPORT sleeve delivers efficiency for ultra-high stage count requirements
- High stage density may increase liquids recovery

Conclusion

Ultra-high stage density is being implemented in most resource plays throughout North America. It appears that this trend will continue in the foreseeable future. With the search for high liquids as well as shortage of fracture equipment throughout North America and around the world, efficiencies are required to meet high stage count demand. The RepeaterPORT sleeve is a key technology going forward, with expectations that greater than 50 stages will be required to effectively drain tight rock in resource plays throughout the world.



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about the author

Dan Themig is the Co-Founder and President of Packers Plus Energy Services headquartered in Calgary, Alberta Canada. He has served in various engineering and technical positions in the U.S. and Canada and has been involved in advanced horizontal and multilateral projects worldwide for over 30 years. He has a B.Sc. in Engineering from the University of Illinois and an MBA from Oklahoma State University. He is a registered professional engineer and a member of SPE.