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Application of Interventionless Single Point Entry Technology to Improve Proppant Placement Control and Well Production

J. Griffin and D.J. Rojas, Stage Completions Inc; A. Al Shmakhy, Abu Dhabi National Oil Company; P. Scranton, Stage Completions Inc

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Abstract

The hydraulic fracture treatment (HFT) and its effectiveness to enhance wellbore drainage directly correlate with each well's overall production performance and underlining economics. This paper will discuss the potential of ultra high stage count Single Point Entry (SPE) sleeves and their ability to increase control over proppant placement and isolation during the HFT as a method for optimizing well performance, economics, and reduce non-uniformity between treatments and wells.

To address the limitations of current completion methods, full ID single point entry systems have been developed for open hole and cemented applications. These systems provide unlimited frac stage count with lower frac tortuosity, provide increased control over proppant placement and well production, reduce or eliminate over- flush and formation damage, and achieve higher efficiency during and after frac stimulation than previous conventional plug-and-perf (PnP) and sleeve systems, thereby reducing costs.

While the ball-and-seat completion technique revolutionized the efficiency of multi-stage single point entry fracturing, its vast array of limitations (primarily ID restrictions), limited stage count, and compatibility with cemented liners quickly sidelined it in place of PnP. PnP offers increased surface area contact through additional entry points compared to sleeve systems of the past and remains the accepted method for achieving zonal isolation and initiation during stimulation. However, the time intensive operations of PnP present challenges in maintaining efficiencies due to variability in wireline during deployment and coiled tubing during millouts. The increase in number of clusters per stage and number of stages per well achieved with PnP often results in higher stimulated rock volumes (SRV) however, due to the number of multiple clusters open simultaneously, this method gained a "pump-n-pray" reputation due to the uncertainty of cluster efficiency and its unpredictability. The lack of cluster control over the years has created a series of challenges in terms of parent-child well relationships and spacing, economical asset development, and loss of potential production.

With over 4,000 stages fracture stimulated across US, Canada, and Asia, some wells containing 220 individual stages, this paper will address the differences in production in terms of bbl of oil equivalent (BOE) for direct and indirect offsets in trials, compare capital efficiency with spud to put on production (POP) timelines, demonstrate economical completion optimization for lower commodity pricing of oil, and carbon intensity reduction measures to lower greenhouse gas emissions.

Introduction

The economics of the commoditized hydrocarbon industry relies on the ability of producers to extract hydrocarbons in the most efficient and profitable ways possible. The application of advancing technologies to proven fields allows operators to increase NPV of assets, increasingly valuable in a fluctuating market. For successful market adoption a technology must address at least one of two issues; decrease capital expenditures or increase ultimate recovery. The ability to achieve both of these targets defines the clearest path to adoption for a technology. Application of interventionless stimulation techniques eliminate the need for wireline and coiled tubing units as well as reduces the number of required pump trucks. With this equipment being a large portion of the completion AFE operators can realize savings by implementing this technology. Along with the reduction of surface equipment single point entry has the ability to improve the quality of the stimulation leading to higher ultimate recovery. This paper will discuss the application of interventionless single point entry technology for a major operator in the Middle East.

Problem Statement

As discussed in the introduction the hydrocarbon industry is based on commodity pricing. Hydrocarbons extracted via new technology do not earn a premium at market. All technologies must provide an economic advantage to the producer to be competitive. Often this economic advantage must be seen as a reduction of costs on the front end of operations. While increased production is always a benefit, this is not a guaranteed and often times not as attractive as upfront cost reductions but does help the continual usage of the product.

Legacy completion operations such as Plug and Perf (PnP) are an industry standard when it comes to stimulating unconventional reservoirs. Setting plugs and perforating via wireline, stimulating, then milling plugs requires both wireline and coiled tubing units to be mobilized. While this operation is a proven technique the economics depend greatly on the service prices of wireline and coiled tubing which vary by the current demand. By eliminating these operations, a producer can price in cost of stimulation and increase their confience in the future economics of completing wells.

Approaching the situation from a design standpoint, a single point entry strategy allows completion designers a higher degree of confidence with fracture initiation as there is only one fracture created at a time resulting in 100% cluster efficiency. PnP designs operate via multiple entry points in a single stage to increase operational efficiencies on location. This often time is at expense of the completion design itself as there is no guarantee that all clusters will be treated with the same proppant and liquid loading and has the potential to create larger fractures than designed and cause interference between multiple wells in a field.

Ultimately, if single point entry technology can address a market at the same operational efficiencies and equal costs as a legacy PnP operations there is a distinct advantage to adopting a single point entry system.

Operational Application

Plug and Perf completions operate by conveying a frac plug and perforating guns via wireline to the target zone. The frac plug is set providing isolation from the previous zone and intervals are perforated along the target zone for reservoir access. The stage is then pumped and the operation repeats. After all stages are stimulated and the frac spread is moved off location the frac plugs are then milled via coiled tubing conveyed tools giving access to the entire wellbore for production. The single point entry equipment covered in this paper operate via tools installed on the production liner which are activated via a pumpdown collet. When the collet reaches the appropriate downhole tool the collet latches in places shifting the tool to the open position. A dissolvable ball and seal stack on the collet provide isolation from the previous zone and the stage is then pumped. After a given amount of time the ball disintegrates providing access to the wellbore for production. In contrast to legacy methods this single point entry method does not require wireline or coiled tubing to bring a well onto production. All tools are picked up and threaded via the production casing run on the drilling rig and do not slow down the pace of the rig.

The major driver for the operator to adopt this technology was the savings due to eliminating the need for wireline and coiled tubing. Pricing for these services were a major portion of their completion AFE (Authorized for Expenditure) and reliability of these operations were also poor, adding to the total time needed to bring wells on production.

Time to complete single wells with PnP operations hinges on time between stages to set frac plugs and perforate intervals as well as the time needed to mill plugs post stimulation. While pump time for stages accounts for a large portion of time to complete the well these times were dependent on fracture design. Slurry density and pump rates are defined by the fracture design therefore they are not as easily manipulated as other operational time savings. Zipper fracturing and simultaneous fracturing are available and quicker than single well stimulation. Zipper fracturing functions by alternating stimulation between two wells through the use of a zipper manifold. This eliminates the nonproductive time waiting on wireline to perforate the next stage. Simulfrac works by splitting the flow of fracturing fluid between two wellbores and treating both at the same time meanwhile two wireline kits perforate the third and fourth wells on the pad. These require more support equipment on a multiwell pad, increasing the footprint of the operation. They also do not address the root concern of this operator by eliminating intervention techniques in their wellbores.

This technology is not the only way to deliver single point entry. It was chosen over two other pinpoint fracturing technologies; ball drop sleeves and coil activated sleeves. Ball drop sleeves posed the problem of limited number of stages, tapered ID, pumping restrictions during stimulation, and milling post completion. To achieve a large number of stages ball drop sleeves must taper down in orifice size towards the toe with extremely tight tolerances. This creates an inability to enter the wellbore with coiled tubing as well as increased frictional pressure caused by each seat. If fluid flow rate were to increase past a certain threshold there is a possibility of prematurely opening one of these sleeves. Post stimulation ball seats must be milled as not to cause sand bridging at the seats. Coiled tubing activated sleeves, as the name implies, use coiled tubing to convey a shifting tool downhole to manipulate sleeves. The tool is set in a sleeve where a packer is used to isolate the zone. Pressure is then increased causing the sleeve to shift to the open position. The frac is then pumped with coiled tubing in place using the packer as isolation. After the zone is treated the tool is then moved to the next sleeve and the operation repeated. This operation requires a coiled tubing unit present throughout the entire stimulation process. Operational risks are increased as downtime due to coiled tubing would require frac fleet standby and vice versa. Possibilities for extended reach wells also diminish with the lock up depth of the coiled tubing available to the operator. While sleeves can be installed to total depth, inability to reach these sleeves with coiled tubing would not allow these stages to be treated. Pushing the limits of coiled tubing would also require the use of pipe on pipe friction reducers. These chemicals can be costly and may affect reservoir properties. On top of this, a one time application would not be sufficient as each stage is pumped the previous chemical is pushed into the formation and more chemical must be re-applied. While both methodologies provide single point entry, they both require coiled tubing at some point of the operation. With a major concern of the operator being the cost and reliability of coiled tubing operations these were not viable options. It is worth noting there is a cost of wellbore construction tools. Any type of sleeve will require installation with the production casing and there will be an associated cost of the tools. The quantity and price will depend on the well parameters and supplier and these must be addressed on a well by well basis. These costs can be mitigated by removal of other equipment (such as frac plugs), cost of intervention service, and increased time on production.

Expected Results

With the unprecedented market effects of 2020, continuing into the early parts of 2021 this particular project has been shifted back accordingly but the expected results can still be discussed to a varying degree. Leveraging previous performance history as well as abilities granted to the operator via the use of these tool can be discussed and evaluated. It is important to note that these tools are only as effective as the completion design they are incorporated into. The role of the service company is to provide the operator with the most flexible tool possible while not imposing limitations to their fracture design. The tool is designed as a single point entry reservoir access tool. To treat a single point entry stage at the same fluid rates and total proppant as a multi cluster stage would produce much different results. Proper planning and execution must be taken when incorporating these tools into a well design because they are not a "plug and play" replacement for legacy operations. This is not to say that these tools are less effective than plug and perf but they do function differently therefore those differences must be taken into account in the design process.

Knowledge of the preferred production metrics for the operator is always the first task when placing this technology. Nationally owned, publicly owned, or private ownership can vary what values take precedent for a given company. National oil companies and those companies operating on government land may tend to focus more on ultimate recovery of an asset. Decline curves being a large player in the evaluation of a new completion strategy. Other may focus on initial production (IP) for quicker paybacks and ROI's. While producing the maximum amount of hydrocarbons is essential to both mindsets the time element plays a very important role for the economics. Single point entry has shown to produce a more attractive decline curve than conventional plug and perf operations (SPE-174943-MS Algadi Et al.) While initial production can vary between the two techniques if IP is the most desirable to the client PnP operations can be modified for high cluster counts to hit IP numbers. This technology addresses both concerns. Ultra high stage counts with the addition of single point entry allows users to treat stages individually without giving up total fracture initiation points. Ball drop systems are not suitable for this application as there is a finite number of sleeves that can be placed in a single wellbore and is capped by the ID of the host casing. Coiled tubing sleeves are limited to the extent of capability of the shifting tool. Tools may need certain amount of space between sleeves to function and shift the respective sleeves. This is most apparent in hydrajetting operations where the tool must be clear of the previous perforations. If the tool is not clear of the previous perforations stage to stage pressure communication via the reservoir or cement channeling can cause inflow and eroded the lower portion of the tool. This applies to sleeves left in an open position as well if spacing is too tight. Using an interventionless actuator that is retained in the tool itself requires no additional space out of the tools. This allows adopters to place equipment along the wellbore wherever they see fit. It also has the benefit of addressing anisotropy in the wellbore as different fractures can be stimulated with different proppant loads and flow rates.

Proppant placement has been addressed in a limited nature earlier in this paper but will be expanded upon here. The concept is simple; if there is only a single entry path to the reservoir and fluid is moving the fluid and proppant is entering at that point. Of course, loss of isolation to the previous zone would prevent this, it is easily detectable on surface with a sudden unexplained drop in treating pressure and is an infrequent event with this technology. Market trends have shown that cluster efficiency is a popular concern in the industry with the introduction and evaluation of limited entry perforation and the use of near wellbore diverter. The goal of these technologies is to evenly spread proppant and rate among all clusters in a given zone. While these technologies are an improvement from previous strategies, they fail to address the root cause of cluster inefficiency. Anisotropy and stress concentrations at that level of resolution are often unknown as well as the erosion of perforations and improper entry of diverters. If perforations are designed to cause a pressure restriction at the casing reservoir face with high rate proppant laden fluids passing through them there will inevitably be erosion. With erosion the perforation diameter will increase and no longer cause pressure restrictions. The entire completion strategy of hydrajetting is built on the concept of using slurry at rate to perforate the host casing. The assumption must be made that all perforations will erode at similar rates to be able to equally treat all clusters in that zone. Near wellbore diverters raise a different issue of directing fluid flow from clusters that are accepting a larger than allotted portion of slurry to those who are not. While in theory this would address the problem of unequal treatment the application is dependent on the ability of these additives to select the proper clusters. Failure to do so could worsen the problem of inequal proppant distribution. The only way to address cluster inefficiency at the root cause is to iniate a single fracture at a time. While this is possible with plug and perf the operational implications would stimy the process. More wireline trips would need to be made and more plugs would need to be milled post fracturing. Ability to open and isolate individual stages with no down time pumping eliminates the operational limitations of single point entry via plug and perf.

While no production data is available at the time this paper is written there is historical data from similar wells in the Permian Basin. The operator used single joint spacing between tools and modified the pump schedule to achieve the same lbs/ft proppant density in the lateral. This allowed for a direct comparison to offset wells in the area when gauging production performance. The program was tested on two pads with two wells a piece for a total of four wells implementing this technology. The first set of wells outperformed the twelve PnP offsets by an average of 11,184 bbls/ 1,000 feet of lateral in the first 10 months of production. The second set of wells outperformed the eleven other PnP offsets by an average of 9,481 bbls/ 1,000 feet of lateral over a 9 month period.

Efficiency Modeling

To effectively evaluate value propositions to adopters an efficiency model must be created to determine time and equipment utilization and savings. Comparison between completion techniques must be determined on an equal basis, such as wellbore parameters, total proppant, and total liquid. A computer model was created to address this concern and to calculate; time needed to bring a well on production, hydraulic horsepower required to stimulate the reservoir, carbon dioxide emissions, and water and diesel usage. General inputs for the model include total measured and lateral depths as well as total proppant. Water to suspend proppant is assumed at 1 lb. concentrations and can be modified to fit specific pump schedules. Since this is primarily a time-based calculator the most important aspect is matching slurry volume per lateral foot. Specific inputs for the completion methodologies include stage spacing, pump rates, and expected treating pressures. Stage spacing allows a total number of stages to be calculated which is important for determining non-pumping operations time contribution. Pump rate and expected treating pressure contribute to hydraulic horsepower requirements as well as fuel consumption.

Multiple completion methodologies were built into this model for comparison although not all will be discussed in this paper. In this instance single well interventionless pinpoint will be compared to single well plug and perf. While greater efficiencies can be obtained using zipper and simulfrac style completions this was not the objective of the adopter.

A model well was constructed with a measured depth of 18,500’, lateral length of 10,000’, and total proppant of 14.5 mmlbs. The plug and perf well was given 200’ stage spacing for a total of 50 stages and an average surface treating pressure of 7,500 psi at 100 bbl/min. The interventionless completion was given single joint spacing (42’) for a total of 239 tools with an average treating pressure of 6,000 psi at 60 bbl/min. Total proppant and water volumes were equal for both cases to give a true comparison. These values were pulled from empirical data from similar formations. These two scenarios were then evaluated in three different sectors; Pressure Pumping Up Time, Additional Frac Operational Time, and Post Frac Coiled Tubing Intervention. All three sectors were then combined to give a total time to completion.

Pressure pumping uptime favored PnP operations solely due to the fact of the higher pump rates achieved. However, these higher pump rates and treating pressures did increase the total hydraulic horsepower needed on location adding increased costs. Interventionless stimulation provided the greatest value for horsepower requirement due to the nature of single point entry with a full wellbore with no pressure restrictions.

Additional Frac Operation time showed the interventionless methodology to be a much quicker because the time needed to convey plug and guns to bottom in the plug and perf scenario. The model did account for time needed to load the ball and collet combination but still outperformed the plug and perf scenario handily, more than overcoming the time difference lost due to pump rate.

Post frac coiled tubing intervention also favored the interventionless methodology. Although the system is interventionless many adopters may elect to run a coiled tubing clean out run before bringing the well on production. This process is a much quicker and simpler process than milling frac plugs and flowing plug debris to surface. Eliminating this step also de-risks the operation because the likelihood of stuck pipe is significantly higher when milling plugs if proper circulation is not achieved.

As mentioned before, carbon dioxide emission, diesel usage, and water usage were also calculated in this model. The interventionless system outperformed the plug and perf scenario in all three categories. Carbon dioxide emissions are directly tied to fuel consumption. This matter is discussed in more detail in a later section, but lower horsepower requirements allowed the interventionless system to burn less fuel reducing emissions. Water savings were also calculated during frac operations. The interventionless system allows the per stage flush fluid to convey the collet downhole saving one wellbore volume of fluid per stage. An additional wellbore volume of fluid is saved at each stage by eliminating the need to pump wireline conveyed perforating guns.

The graphics below show the results of the model.

Environmental, Social, and Governance Considerations

With growing considerations for environmental, safety, and governance (ESG) there has been a major push for corporate action to reduce carbon footprint in their operations. From a service standpoint in completions, fuel consumption for operations is the largest contributor to CO_2 emissions. For hydraulic fracturing large amounts of horsepower is needed to transport proppant laden fluids downhole at high rates. Pinpoint fracturing reduces flow rates needed for stimulation because only a single fracture is created at a time. Plug and perf relies on stimulation of multiple clusters within a single stage requiring a higher flow rate to accommodate this. By reducing the flowrate in the wellbore frictional pressure is lowered so surface pumps work against lower treating pressures, reducing fuel consumption. From modeling done on typical wells on US land, application of this specific interventionless technology can reduce fuel consumption and CO_2 output from 25% - 30% dependent on completion design. This number is tied only to the pressure pumping aspect of the operations. Additional fuel and CO_2 emissions savings come from the removal of wireline and coiled tubing from location during and post fracturing. While these savings are significant, quantification becomes more difficult without specific parameters.

The second prong of ESG, safety, has been an ever-present concern in the Oil and Gas industry. Legacy hydraulic fracturing treatments deal with heavy equipment, high pressure, and explosives. Implementation of this interventionless technology has allowed operators to reduce footprint on location as well as reduce personnel around the wellhead. A hydraulically actuated collet launcher is used so no personnel is needed for valve swapping operations in the red zone. Eliminating shaped charges on location removes the risk of accidental discharge in the wellbore on surface. Pulling a perforating gun from the wellbore after a misfire is a high risk, slow moving safety operation.

Table 1—Model Parameters and Inputs

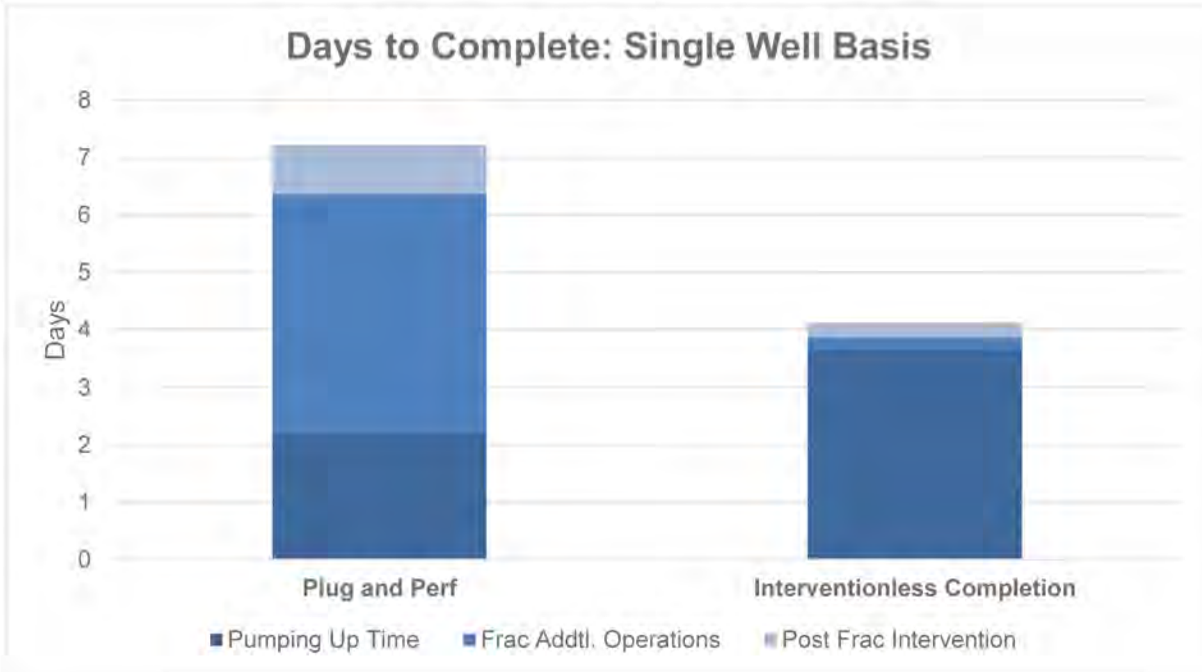
Well Parameters	Plug and Perf	Interventionless Completion	Unit
Total Measured Depth	18,500	18,500	ft.
Lateral Length	10,000	10,000	ft.
Total Proppant	14.5	14.5	mmlbs
Stage/Tool Spacing	200	42	ft.
Total Stages/Tools	50	239	
Pump Rate	100	60	bbl/min
Avg. Treating Pressure	7,500	6,000	psi

Table 2—Itemized Days to Complete Single Well

Days to Complete	Plug and Perf	Interventionless Completion
Pumping Up Time	2.19	3.65
Frac Operations	4.17	0.21
Post Frac Intervention	0.86	0.26
Total Days	**7.22**	**4.12**

Table 3—Resources, Emissions, Consumption

Resources	Plug and Perf	Interventionless Completion	Unit
Hydraulic Horsepower	22,054	10,586	horsepower
Number of Pumps	14	7	
CO_2 Emissions	985.9	573.7	tonnes
Diesel Consumed	97,049	56,475	gallons
Water Used	345,187	315,217	bbls



Graph 1—Days to Complete Single Well

Conclusion

In conclusion the technology demonstrated in this paper provided the correct value add for the customer by reducing initial costs as well as creating an environment for increased production. The use of interventionless completion was a hinge point for their economics in unconventional reservoirs. Removing the cost of wireline and coiled tubing was more than enough to offset the costs of the completion equipment. In addition to the cost savings to the customer, they are able to utilize pinpoint fracturing to fine tune the treatment as well as leverage ESG benefits.

References

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