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Method and Apparatus for Simultaneous Stimulation of Multi-Well Pads

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Abstract

Progressively, the oil and gas industry is producing from unconventional reservoirs with low permeability in numerous small pay zones that require close well spacing and multiple stimulations in each well. To effectively produce from such reservoirs and reduce the surface footprint, ExxonMobil has drilled multiple wells from single pads, and new technologies have been developed to efficiently stimulate the multiple pay zones in each well.

ExxonMobil has developed and licensed Multi-Zone Stimulation Technologies (MZST), which are designed to efficiently stimulate wells with multiple pays zones. The technologies have been applied in fracturing tight gas reservoirs with numerous lenticular sands in the Rocky Mountains. We have also developed a technology that enables the simultaneous stimulation of multiple wells on the same or different well pads, and while drilling additional wells. The benefits of this technology include reduced environmental impact, time saving, and improved production rates. Most importantly we have demonstrated that these simultaneous operations can be conducted in a safe and responsible manner to ensure the highest standards of operations integrity.

This paper introduces the method and apparatus for this technology and discusses the results from several years of field applications, including the Piceance Basin. Some specific elements of the simultaneous operations safety plan will also be provided.

Introduction

Worldwide, substantial oil and gas resources are contained in low permeability formations. Many of these resources are characterized by thick intervals and/or multiple reservoir targets. In addition, matrix or fracture stimulation treatments are typically required to effectively and optimally produce these resources. However, the increased geologic and reservoir heterogeneities present in these resources can lead to substantial challenges in the stimulation treatment operations and effectiveness.

Over the last several decades, industry has invested substantial research in attempts to develop new drilling and completion technologies for application in tight gas sand reservoirs. Various government and industry studies indicate a vast amount of tight gas resources exist within the United States alone, with similar resources located outside the U.S. Examples of such resources are found widely distributed in the western United States, and include the Green River, Piceance, Wind River and Uinta Basins.

To address these challenges, ExxonMobil has focused on developing novel "Multi-Zone Stimulation Technologies" (MZST), consisting of hardware and procedures to substantially improve stimulation treatment placement and effectiveness in very thick reservoirs. MZST allows the stimulation of reservoir intervals that normally would be bypassed, thus increasing: (1) the production rate per well; and (2) the total hydrocarbon recovery. Additionally, resources that require numerous stimulations to become economic ventures can be "enabled" via the application of MZST. In the Piceance Basin, with nearly 300,000 gross acres under lease with a potential recoverable resource of nearly 45 trillion cubic feet of gas, MZST is being used by ExxonMobil, in its operated acreage, to maximize recovery and per-well production rates while reducing

development costs and the environmental footprint. This largely undeveloped tight gas resource has been known to industry for well over 50 years and presents a challenging test for any fracture stimulation technology. The formation is characterized by a thick reservoir section (up to 5,000 feet) that is comprised of numerous vertically stacked lenticular sands with effective permeabilities as low as approximately 1 micro-Darcy. Figure 1 shows the location of the Piceance Basin, an outcrop of the lenticular sand bodies, and a typical grain cross section. Figure 2 shows the conceptual approach for MZST.

The two MZST methods are referred to as "Just-in-Time Perforating" (JITP) and "Annular Coiled Tubing Fracturing" (ACT-Frac). These technologies enable: (1) the delivery of a large number of stimulation treatments (e.g., 40+ treatments) in a single well over an extended reservoir interval and in a timely manner; (2) effective diversion between treatments to improve placement of treatments specifically designed for each target zone; and (3) the ability to pump treatments at high flow rates to ensure efficient and effective stimulation¹. This paper will focus on the JITP technology and associated technology advancements.

To establish further synergies, ExxonMobil has also developed a technology that enables the simultaneous stimulation of wells on the same or different well pads with or without the drilling rig continuing operations². This technology: (1) minimizes the surface footprint; (2) results in time and cost savings compared to sequential well stimulation operations; and (3) realizes earlier production in the wellbore manufacturing life cycle. We have successfully applied this type of simultaneous operation by means of highly trained and motivated personnel, rigorous completions and operational procedures, and implementation of a well established, structured, safety, health, and environmental management system.

JITP Stimulation Method

A well is stimulated using the JITP method by sequentially treating individual zones via the combination of selectively perforating single intervals and promoting the isolation of these intervals through the deployment of ball sealers. A single continuous pumping operation allows uninterrupted operations as well as positive pressure on the ball sealers to facilitate and maintain effective fluid diversion.

Several technical areas needed to be addressed and refined during the course of the JITP technology development and field deployment: (1) ball sealers must reliably flow past the BHA during pumping operations; (2) the BHA must not become differentially "stuck" to the perforations while a treatment is being pumped (caused by the radial pressure gradient that drives the treating fluid into the perforations); (3) balls must tightly seat against perforations to mitigate leakage and ball sealer erosion; (4) if a pumping operation is interrupted, balls should be capable of re-seating when pumping is re-initiated; (5) the perforating operation must be properly timed to ensure that the balls have passed the BHA before the next gun is fired; and (6) if the stimulation treatment fluids are staged (e.g., varying fluids and/or proppant concentration), then proper arrival of the ball sealers is important.

Figure 3 is a schematic of the JITP bottom hole assembly (BHA). It is designed to include decentralization, allowing the ball sealers to reliably flow past the BHA during pumping operations. Decentralization maximizes the unrestricted cross-sectional area available in the wellbore to facilitate unhindered ball sealer passage. The diameter of the gun barrels are also sized to maximize the available unrestricted cross-sectional area while still providing a sufficient perforation charge to ensure reliable and effective communication with the formation.

Stand-offs are included in the JITP BHA as a means of mitigating differential sticking issues for zero phased guns that can arise from firing perforating guns in over-balanced and continuous pumping conditions. Note that phased perforating (our current best practice for Piceance Basin) does not require offset rings. The radial gap provided by the stand-offs prevents the guns from covering the perforations and provides a flow path for treatment fluids to enter the perforations, thus minimizing the "sticking" effect and allowing the gun assembly to be pulled up-hole. Of course this standoff, and the associated restriction in the wellbore flow passage, has to be balanced with the first requirement of reliable ball sealer passage.

Figure 4 illustrates the JITP stimulation process. If zones have already been stimulated, the gun assembly is run with a bridge/frac plug and setting tool, and the plug is set below the first zone to be stimulated. After setting the plug, the gun assembly is positioned at the first zone and the first gun is fired. The gun assembly is then raised to the next zone of interest and the first treatment is pumped. At the tail-end of the treatment, ball sealers are added to the flow, with at least one ball sealer for each perforation. When the ball sealers arrive downhole and seal the perforations, as evidenced by a sharp rise in wellbore pressure, the next gun is fired and the second treatment is initiated without ever shutting down the pumps. This process is repeated for as many zones as there are individual guns on the deployed assembly. Once all the target zones have been stimulated, the gun assembly is retrieved. This process, or JITP event, is then repeated until the entire well has been completed.

To promote effective fluid diversion and robust response during upset conditions, the ball sealers used for JITP are made of rubber-coated syntactic foam and are uniquely designed to maintain buoyancy under high pressure/high temperature conditions. Buoyancy is necessary to ensure that balls migrate uphole during temporary interruptions to pumping operations (upset conditions) thus enabling balls to re-seat once pumping operations are re-initiated.

Approximately five zones are stimulated during a single pumping operation as determined by the ball-out pressure response, and in some instances as many as 12 zones have been stimulated in a single operation. Bridge or frac plugs are deployed between pumping events to isolate the previously placed set of treatments. After all the desired zones in a well have been treated, the plugs are drilled out and the well is placed on commingled production.

Simultaneous Operations

Simultaneous operations technology has enabled ExxonMobil to gain full benefit from efficiencies in the JITP operations. In the Piceance Basin, as shown in Figures 5 and 6, up to nine wells, with surface locations spaced about 15 ft apart are drilled from a single pad. The advantage is that the drilling rig, and later the fracturing equipment, can move easily from one well to the next without having to travel and set up at a new location. More specifically, the technology enables sequential pumping operations on multiple wells without suspending fracturing operations while waiting for non-pumping events (such as wireline rig up and running, setting frac plugs, etc.). In this manner, crews are more effectively utilized and the overall completions time greatly reduced. Of significant benefit is the reduced working footprint and reduced environmental impact from repeated equipment mob/demob operations.

The major components in the simultaneous operations are a stimulation fluid storage system, a stimulation fluid pumping system, a manifold system to enable stimulation fluids to be directed to any of the wells on the pad, flowline manifolds, two cranes, two wireline units, JITP tools, and a coiled tubing unit. Figure 7 shows a typical wellhead and piping layout for simultaneous operations. Multiple wellheads are connected together from the high pressure pumps through a single manifold. By configuring the valves prior to pumping fluids and proppant, the stimulation operator can choose which well will be treated and avoid the potential hazards and time delays associated with rig up and rig down of high pressure lines multiple times over the course of many days. In order to accommodate this treatment schedule, wireline trucks and associated support equipment are placed at each wellhead to support the stimulation operations (setting plugs, perforating, etc.). Individual choke manifolds are installed on each well to accommodate flow back and recovery of fluids used to transport the proppant through the well bore

Since the simultaneous operations technology was first applied, there have been considerable advances in the fracturing operations resulting in additional cost and time savings. For example, cross-linked gel fluids were initially used; however, as experience grew, there was a transition to slick water fracturing. For five-stage JITP hydraulic fracture treatments on wells that are approximately 12,000 ft deep, pumping is performed at an average rate of about 30 barrels per minute. As a result the pumping time for a five-stage treatment is about 2 hours. Wireline is run down the wellbore at approximately 150 ft/min. As a result, the time to deploy the JITP tool at the desired location in the wellbore and to set the frac plug beneath the desired five-stage treatment is also about 2 hours. Thus, the efficiencies for the 12,000 ft well depth are realized. The JITP fracture treatment requires approximately the same amount of time as running the JITP tools on wireline in a second well.

Table 1 illustrates the simultaneous operations for a set of well sequences. Prior to simultaneous operations, it is assumed that each well had been drilled, cased hole logged and was ready for completion, but were at different points of the overall JITP process. The "JITP assembly" refers to the wireline-deployed JITP perforating gun and frac plug setting system having a composite frac plug. This example clearly shows that three fracture treatments can be conducted sequentially in one working day or in many cases as little as seven hours. Crews are efficiently utilized with minimal waiting on non-pumping operations. The wells are allowed to flow back to unload the treatment fluids and to allow recycling of fluids. At the end of the last treatment, a coiled tubing rig is brought in to drill out the plugs, and a completion rig is used to run tubing into the wells to enable commingled production testing. One of the major benefits of the simultaneous operations is the ability to accelerate the application of learnings from one well to the next. For example, results from flowback operations can quickly be applied in the design and application of a fracture treatment in another well, almost on a real time basis.

Referring again to Table 1 and Sequence 1, it should be noted that running (or deploying) a JITP assembly in Well 2 while pumping a five-stage fracture treatment in Well 1 has become an established practice. Should an upset occur during pumping in Well 1 for any reason, pumping can quickly be initiated in Well 2 with a 15 minute turn around time. Pumping in Well 2 will usually be under way while wireline is being removed from Well 1. Once the wireline is removed from Well 1, it can be redressed for a new deployment and returned to Well 1, if needed, or Well 3 as denoted in Table 1, depending on that day's strategy for sequential fracturing operations.

Cost savings realized on a non-dimensional cost per frac basis are shown in Figure 8. The cost savings over time are due to full implementation of the simultaneous operations technology. Additionally, fracture fluid systems have evolved from a cross-linked gel to the current practice of slick water fracturing. Ceramic proppants, with a loading of 5-6 ppg) were initially used with the cross-linked gel. Currently white sand at a much lower cost and a loading of 2-3 ppg are used in the slick water fracturing operations. Thus cost per fracture is now about 50% of what it was initially.

Drilling Operations

Many drilling rigs today have derricks that can “skid” in both the X and Y axis. This enables the rig to continuously drill on a pad for up to 22 wells in some cases without moving the supporting equipment such as generators, mud tanks and mixing equipment, etc. Completion of a well while drilling the next has the potential to further reduce cost and release stranded capital investments (cash flow) prior to complete release or FRR of the rig on that location. This technology economically enhances the investment while employing real time lessons learned.

Cased hole logs can be run, obtaining needed information on formation and cement tops for early well completion planning. Early completion results may influence stimulation decisions for offset wells and zones. Everything from water avoidance to enhanced cement job design and practices can be measured and evaluated prior to drilling and completing many wells on the same pad. A real time feed-back loop of data can be established for teams managing results from actual vs. theoretical data.

Operations Integrity

It was recognized that additional risks and hazards can occur with multiple operations occurring simultaneously with more than one wellbore on the same location. For this reason a dedicated organizational structure was put in place. More specifically, the incremental complexities associated with the multi-well completion process were addressed with the establishment of a “Natural Safety Leadership Team (NSLT), formed with representatives from Health, Safety Environment (HSE), technical, and operations. Flawless communication systems were established for each area of operation, with overall coordination residing with the Person-In-Charge or PIC. The NSLT was responsible for coordinating the morning safety meetings with the contractor crews and also conducting a closeout review at the end of each day to assess “what went well” and what areas need to be strengthened.

A key element of ensuring operations integrity was a Simultaneous Operations Hazard Identification and Mitigation Matrix. In summary, this matrix identified potential hazards, mitigators, and actions required and more specifically identified activities that were restricted from occurring at the same time (i.e., CAN NOT OCCUR activities). As an example, if the operations on a well involved high pressure pumping or JITP ball sealing pressure events, then manipulating manifold well valves and wellhead trees valves on another well were not allowed to be performed concurrently. When operations on a well involved high pressure pumping, then operations on a second well, such as arming the perforating gun or setting tool and picking up or laying down the perforating tool or setting tool, required lights and audible notifications.

Critical to maintaining safety, quality and schedule were proper and sufficient isolation of fracturing fluids. To accomplish this, a minimum of two positive stops or valves were closed during any given isolation from the other wells. The current configuration afforded three valves. These included a minimum of one “ground” valve and two gate valves on each injection head. Valves were marked in the OPEN position during all operations. The default position upstream of the wellhead was always the CLOSED position.

Communications are essential to the safety and efficiency of the simultaneous operations. It was recognized early on that wireless headsets are commonly used by contractor crews during fracturing operations. When a perforating gun is armed and placed in the wellbore or removed from the well all radios were either stored in a central location away from wireline operations in the “off” position and/or each individual with a radio or cell phone was checked to ensure their device had been turned off. Recognizing that pumping operations would need to continue during wireline gun rig up and rig down, “hard-wired” radios were used. In the unlikely event of a total or partial failure of the wired radio system, back up wireless units were on site. Wireless radios were allowed to be used when all armed guns were at least 1,000 ft or deeper in the well, and only then with strobe-warning lights on the active crane. The PIC and contractor lead supervisors personally coordinated this activity.

A drawing of all piping for flow back operations was reviewed for each individual wellhead and all points where flow was commingled for cleanup and/or sales. This operation was expected to continue through fracturing and drill out of plugs in each wellbore. A flow back lead supervisor along with the PIC and field foreman reviewed and approved the drawing for operability. Flowback testers were equipped with portable Lower-Explosive Limit (“LEL”) detectors. During the flowback operations, the flowback personnel continuously monitored the location for the presence of hazardous gas levels. If

hazardous gas levels were detected on location, the flowback would be suspended and appropriate corrective action taken. Windscreens were installed at various points and heights on the location to aid in determining wind direction.

JITP Piceance Basin Field Experience

JITP has been used and refined over the past eight years in the Piceance Basin in the Western United States of America where ExxonMobil holds a large acreage position. In the Piceance Basin, ExxonMobil will drill nine wells on a single surface pad of approximately six acres. These wells target gas-productive reservoir targets at approximately 20 acre spacing. Well depths range from 12,000 to 15,000 ft with lateral throws of 1,400 to 2,000 ft. Each well includes up to forty or more reservoir targets. Using simultaneous operations and the JITP fracture treatment process, at least 20 zones may be pumped during each work day. Forty zones can be stimulated in two to three work days. Thus, approximately one or two days associated with waiting on non-pumping time may be saved on each well. Extending these time savings to the full nine-well program is apparent.

To date, over 2500 proppant fracture treatments have been successfully pumped in over 70 vertical and S-turn wells having 4-1/2-inch or 5-1/2-inch production casing. Most all of the completions have been performed taking economic advantage of the simultaneous operations approach. Zones have been stimulated at depths of 14,700 ft MD, formation temperatures up to 320°F, and maximum surface treating pressures up to 9,500 psi in three wells at the same time.

Recent field experience has demonstrated that this technology can be used to rapidly perform multiple stimulation treatments that result in wellbore production that generally exceeds that obtained from more traditional methods. Figure 9 shows a plot of cumulative production as a function of time for Piceance Basin wells that have been stimulated with JITP compared to nearby offset wells that have been stimulated with various conventional methods. These basins are characterized by substantial reservoir and geologic heterogeneities. Variables impacting reservoir performance include completion practices, permeability contrasts, reservoir pressure, natural fractures, and faulting. The *Multi-Zone Stimulation Technology* and *Conventional Approach* bounded regions labeled in the figure outline raw production data from 55 MZST-wells and 23 conventional-wells completed in the Mesa Verde section of the Piceance basin. Compared to conventional approaches, MZST provides a significant improvement in the ability to quickly generate many high quality fractures.

Conclusions

MZST technology combined with ExxonMobil simultaneous operations technology provides an increased utilization of equipment and manpower previously unheard of. It has the potential to make any multiple pad well site a real time feedback environment allowing continuous improvement in both execution and reservoir understanding; thus enabling optimization of the implemented preplanned investment. Most importantly we have demonstrated that this technology can be applied in a safe and responsible manner following a structured operations integrity program.

Acknowledgements

The authors would like to recognize the integrated teamwork that was necessary for the success of the simultaneous operations technology. The team included members of ExxonMobil Production Company and ExxonMobil Upstream Research Company with both technical and operations expertise. Operations integrity is a guiding principle within ExxonMobil and the authors would also like to recognize the dedication of the technology team in upholding these standards to ensure a truly safe operation.

References

1. Lonnes, S.B., et al: "Advanced Multizone Stimulation Technology", SPE 95778, 2005 SPE Annual Technical Conference and Exhibition, Dallas, Texas, October 2005.
2. Tolman, R. C., et al: "Method and Apparatus Associated with Stimulation Treatment for Wells", World Intellectual Property Organization WO 2207/024383 A2, International Publication Date March 1, 2007.

Sequence	Well No. 1	Well No. 2	Well No. 3
Initial Conditions	JITP assembly in place in the wellbore and ready for 5-stage fracture treatment (Crane 1)	5-stage fracture treatment completed and flowed back. JITP assembly at surface and ready for deployment down the wellbore (Crane 2)	5-stage fracture treatment completed and JITP assembly out of the wellbore. Ready for flowback.
1	First five-stage fracture treatment conducted. JITP assembly removed from the wellbore (Crane 1). ~3 hours	Deploy JITP assembly down the wellbore and set frac plug for 5-stage fracture treatment (Crane 2). ~3 hours	Flowback operations from 5-stage fracture treatment
2	Flowback operations from 5-stage fracture treatment	Second five-stage fracture treatment conducted. JITP assembly removed from the wellbore (Crane 2). ~3 hours	Deploy JITP assembly down the wellbore and set frac plug for 5-stage fracture treatment (Crane 1). ~3 hours
3	Deploy JITP assembly down the wellbore and set frac plug for 5-stage fracture treatment (Crane 2). ~3 hours	Flowback operations from 5-stage fracture treatment.	Third five-stage fracture treatment conducted. JITP assembly removed from the wellbore (Crane 1). ~3 hours

Table 1: Simultaneous stimulation operations sequences

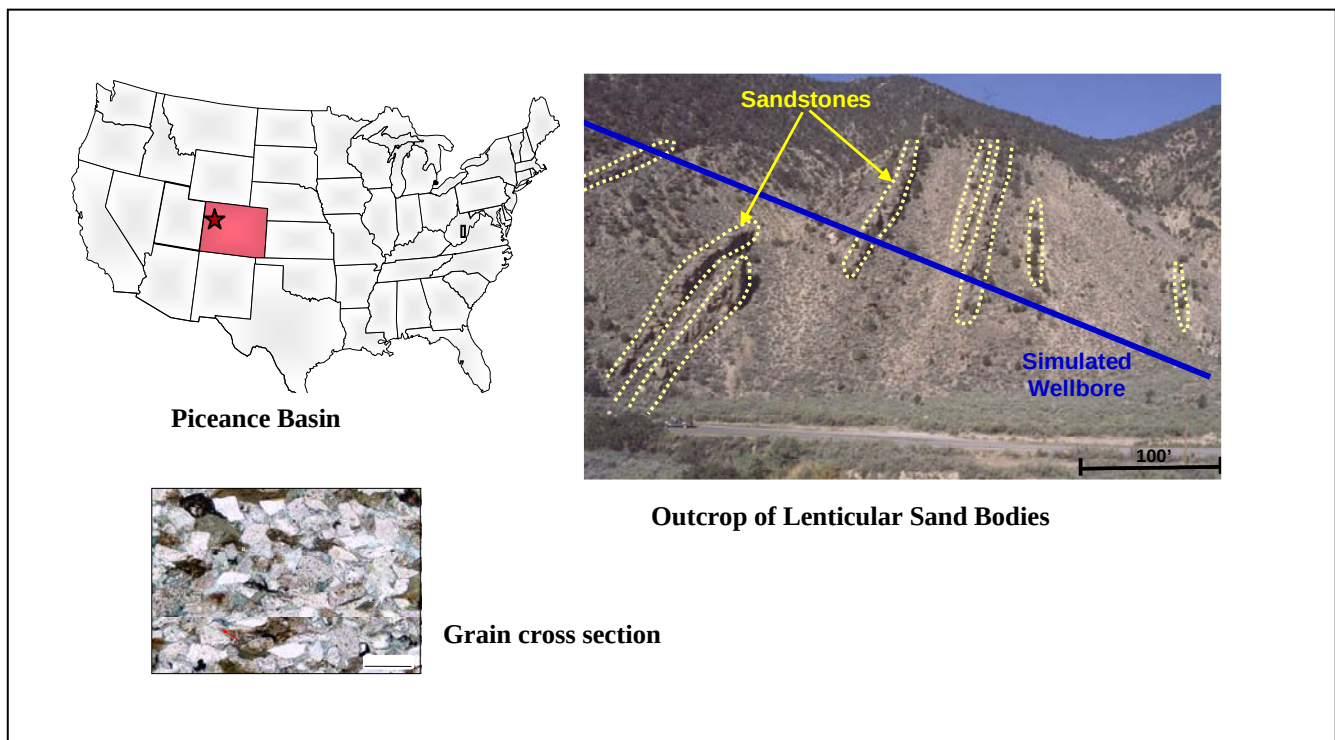


Figure 1: Tight gas opportunity

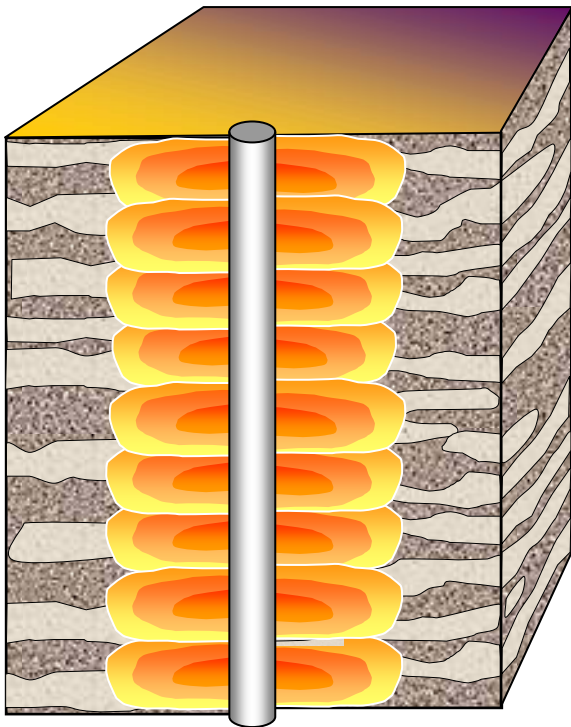


Figure 2: Multi-Zone Stimulation Technology (MZST) concept

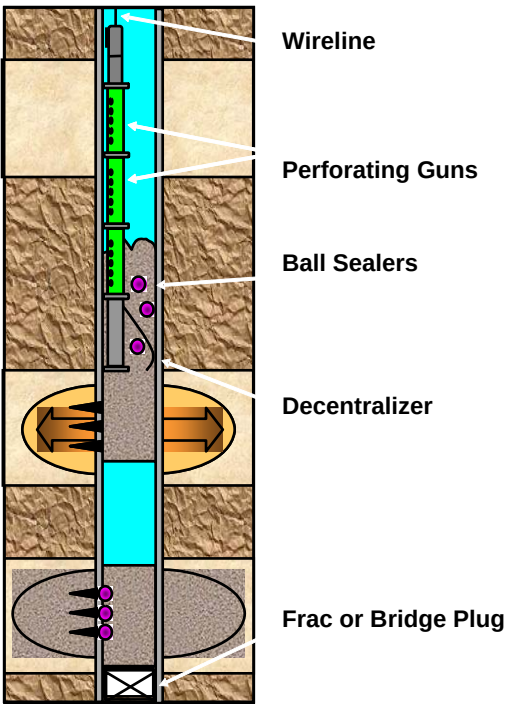


Figure 3: JITP bottomhole assembly

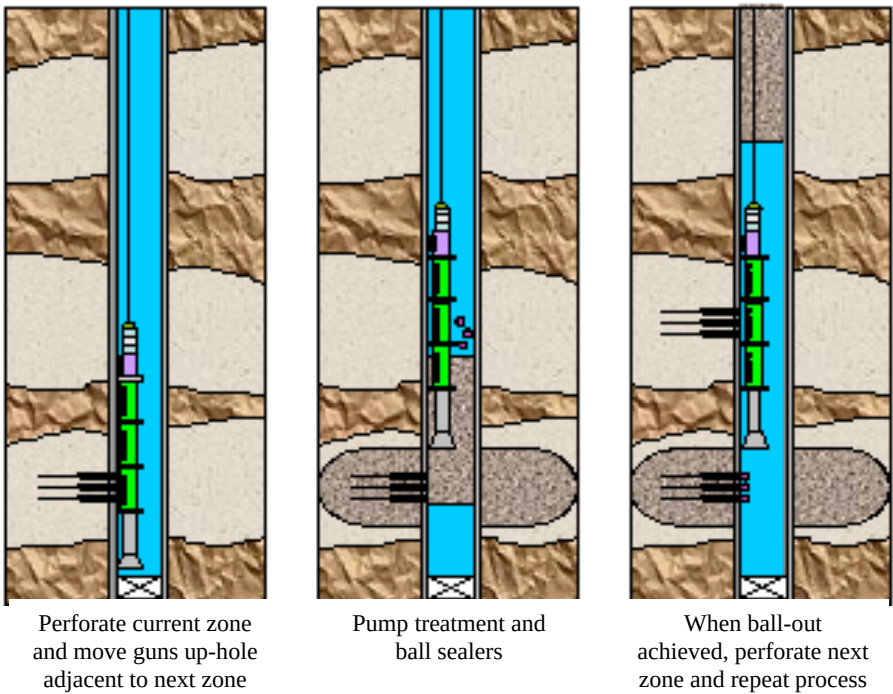


Figure 4: JITP stimulation process



Figure 5: Well pads in the Piceance Basin

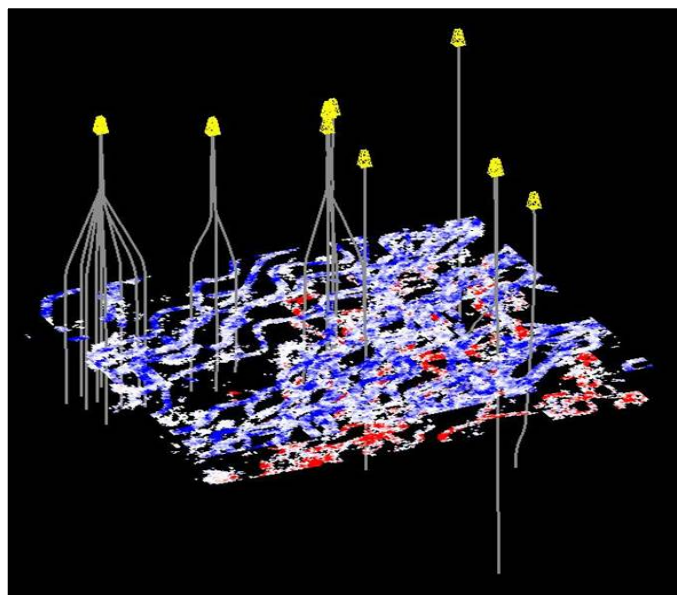


Figure 6: Well configurations from individual pads



Figure 7: Multi-well simultaneous stimulation operations showing wellhead and piping layout

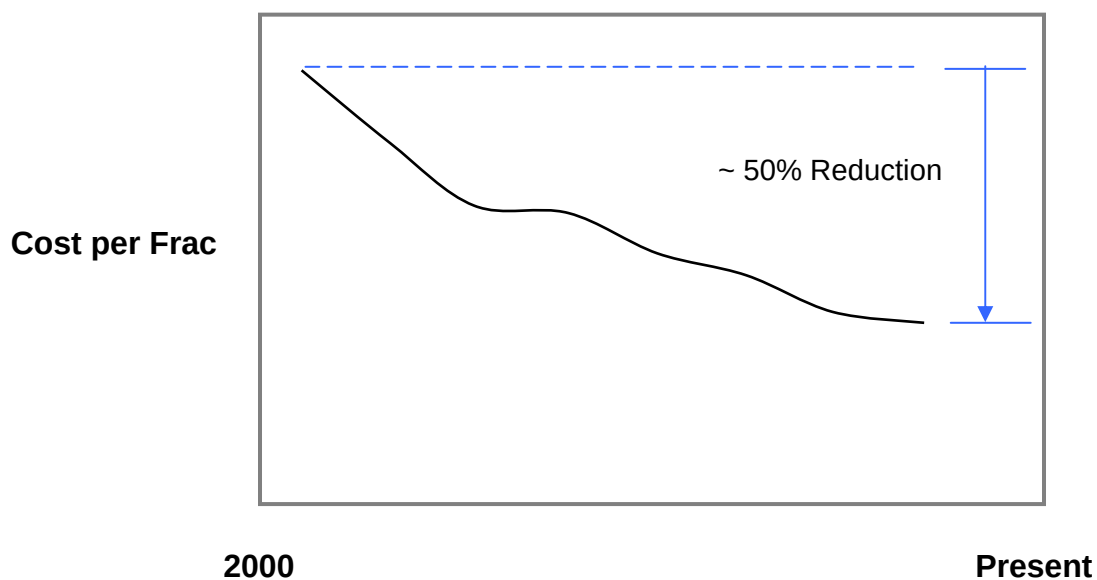


Figure 8: Cost per frac reduction using simultaneous stimulation operations technology

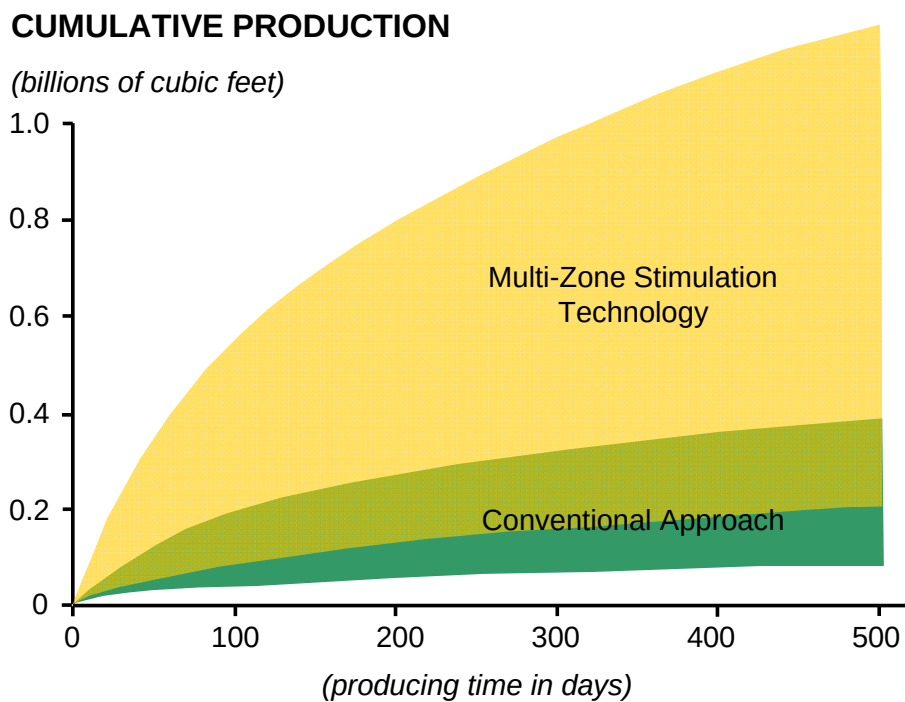


Figure 9: Piceance basin production comparison