GasGun®
Propellant Stimulation

Since 1994 The GasGun, Inc. has provided low cost fracturing solutions to operators with over 10,000 stimulations conducted worldwide.

www.TheGasGun.com
What is the GasGun?

The GasGun is a solid-propellant fracturing device based on proprietary ballistic technology from the U.S. military. It incorporates the most advanced design on the market with the use of progressively burning propellants that have been proven by independent research to be many times more effective in creating fractures and increasing formation permeability.

Since 1994 The GasGun, Inc. has provided low cost fracturing solutions to operators with over 10,000 stimulations conducted worldwide. Our third-generation patented design, introduced in 2004, vastly improved the tool’s performance and fieldability. Its unrivaled success in the field is a direct result of our commitment to the continued development of state-of-the-art propellant fracturing tools.
The GasGun® was originally conceived by scientists at Sandia National Laboratories in the late 1970’s. Over the next few decades, research and development continued to advance the technology and explore its commercial applications. It is safe to say that we have the scientific process in our DNA. We at the GasGun continue to refine the technology, recording and analyzing field results by communicating with all of our customers. Not only is this good science but a great opportunity to provide customer service.

Our extensive database of results, provided by discussions with valued customers, is the foundation for applying the GasGun successfully in real world conditions. It is only when we speak to thousands of customers who have used the GasGun that we generate a large enough data set to clearly understand which downhole conditions present the greatest opportunity for success.

Visit our website or contact us directly and our technical team will review your application today!

+1 503.557.1370
www.TheGasGun.com
info@TheGasGun.com
- Cost effectively stimulate long intervals
- Fractures created along the entire pay zone
- Minimal onsite equipment
- Environmentally friendly

- Zone isolation achieved without packers
- No adverse effects to borehole integrity
- Fractures not dominated by earth stresses

- Fractures created at every perforation tunnel
- Improve effectiveness of acidizing

- Remove skin damage from perforators, drilling, scale, cement, etc.

- Reduce tortuosity and resulting screen-outs
- Break down formation/reduce treating pressures
- Create fractures in preferred plane

- Reduce injection pressures
- Create homogeneous injection profile

- Improve effectiveness of spotting acid
- Break down formation/reduce treating pressures
- Etch channels in newly created fractures

- Increase injection rates

- Significantly improve formation drainage
- Multiple fractures intersect natural fractures

- Zone isolation achieved without packers
- No adverse effects to borehole integrity
- Fractures not dominated by earth stresses
The GasGun generates high pressure gases at a rate that creates a fracturing behavior dramatically different from either hydraulic fracturing or explosives. The goal is to tailor the pressure-time profile to produce multiple fractures which provide optimum nearbore drainage.
4.0” GasGun® System
4.000” OD/2.750” ID High Strength Steel Carrier

The GasGun is a solid-propellant well-stimulation device based on proprietary ballistic technology from the U.S. military. It incorporates the most advanced design on the market with the use of progressively burning propellants that have been proven by independent research to be many times more effective in creating fractures and increasing formation permeability.

Features

• Most powerful GasGun tool available.
• Creates multiple radial fractures into the formation up to 50 feet from the wellbore.
• Designed for 7” casing and larger or 6” open hole and larger.
• Generates nearly twice the energy of the 3.375” / 86mm OD system resulting in longer and wider fractures.
• Wireline and tubing-conveyed systems available for both vertical and horizontal wells.
• Reusable high strength steel carrier and subs.
• Arming procedures comply with API RP-67.
• Patented design.

Applications

• Minimal vertical fracture growth avoids problems often associated with hydraulic fracturing.
• Removes skin and cleans up the wellbore damaged by perforators, drilling fines, cement, paraffin, mud cake, etc.
• Improves effectiveness of acidizing by fracturing first with the GasGun.
• Enhances production in naturally fractured reservoirs by intersecting more fractures.
• Prepares well for hydraulic fracturing by breaking down formation first.
• Reduces injection pressure and improves flow rates in injection and waste disposal wells.

Hardware Specifications

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Warning: Exceeding the maximum temperature ratings can result in unintentional detonation
* 280°F (138°C) maximum temperature rating is for a 1-hour exposure;
260°F (127°C) maximum temperature rating is for a 10-hour exposure.

Miscellaneous Information

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The GasGun is a solid-propellant well-stimulation device based on proprietary ballistic technology from the U.S. military. It incorporates the most advanced design on the market with the use of progressively burning propellants that have been proven by independent research to be many times more effective in creating fractures and increasing formation permeability.

**Features**
- Most widely used GasGun tool on the market.
- Creates multiple radial fractures into the formation up to 35 feet from the wellbore.
- Designed for 4.5” casing and larger or 3.875” open hole and larger.
- Wireline and tubing-conveyed systems available for both vertical and horizontal wells.
- Reusable high strength steel carrier and subs.
- Arming procedures comply with API RP-67.
- Patented design.

**Applications**
- Minimal vertical fracture growth avoids problems often associated with hydraulic fracturing.
- Removes skin and cleans up the wellbore damaged by perforators, drilling fines, cement, paraffin, mud cake, etc.
- Improves effectiveness of acidizing by fracturing first with the GasGun.
- Enhances production in naturally fractured reservoirs by intersecting more fractures.
- Prepares well for hydraulic fracturing by breaking down formation first.
- Reduces injection pressure and improves flow rates in injection and waste disposal wells.

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Features
- Engineered for thru-tubing and other slimhole applications.
- Reduce cost by eliminating the need to remove tubing prior to stimulation.
- Creates multiple radial fractures into the formation up to 20 feet from the wellbore.
- Designed for 2.875” tubing/casing and larger.
- Wireline and tubing-conveyed systems available for both vertical and horizontal wells.
- Expendable high strength steel carrier.
- Arming procedures comply with API RP-67.
- Patented design.

Applications
- Prepares well for hydraulic fracturing by breaking down formation first.
- Removes skin and cleans up the wellbore damaged by perforators, drilling fines, cement, paraffin, mud cake, etc.
- Improves effectiveness of acidizing by fracturing first with the GasGun.
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Over the last 40 years oilfield service providers have performed tens of thousands of propellant stimulations for oil and gas companies all across the globe. Despite their widespread use, propellant stimulations account for a small part of the overall fracture stimulation market, and their applications have not been well understood by most operators. Historically, propellant tools have been applied in wells as either a pre-treatment to hydraulic fracturing or in wells where hydraulic fracturing is uneconomical. With advancements in the safety, reliability and design of propellant tools along with the accumulated knowledge from decades of use, oil and gas companies are finding new applications for this maturing technology.

**Background**

Oil and gas wells have been stimulated with high explosives since the late 1800s. This form of stimulation is often referred to as “well shooting”. Problems of wellbore damage, safety hazards and unpredictable results have reduced the relative number of wells stimulated with classic high explosives, and this method has largely been replaced by the use of propellants.

The solid propellants used in these stimulations deflagrate rather than detonate. Unlike explosives, the burn front in these materials travels slower than the sound speed, and the burn rate can be tailored to fit a wide range of applications. Pressure/time behavior of propellants differ from explosives in that peak pressures are lower and burn times are longer. The approximate values of peak pressure and duration noted for the intermediate pressure pulse of Figure 1 are for the GasGun®, which is one of the propellant stimulation devices commercially available today.

**Common applications**

Early success with the GasGun in the Appalachian and Illinois Basins provided the impetus to expand the service throughout the USA and international markets, with over 5,000 stimulations being conducted over the last decade. As is true with many emerging technologies, the majority of these stimulations have been performed for small independent operators in the USA. Due to its low cost and minimal onsite equipment these operators have found the GasGun to be an economical method of stimulating marginally producing wells. In recent years, the large independent oil and gas companies have begun to recognize the merits of propellant stimulation technology and have been applying it in a wide range of applications with regularity.

In specific applications, propellant stimulation technology has some distinct advantages over other stimulation methods. This has resulted in the routine use of propellant tools, and some of the most common applications for the technology will now be described.
Log Time
Log Pressure

EXPLOSIVE:
~1,000,000 psi
~1 microsecond

GasGun:
~20,000 psi
~10 milliseconds

HYDRAULIC:
~5,000 psi
~1 hour

When designed properly, propellant tools create multiple radial fractures extending from the wellbore. This fracture pattern is illustrated above the GasGun heading in Figure 2. This provides superior nearbore permeability. These multiple fractures are created in a matter of milliseconds, which allows the vertical growth of the fractures to be controlled. As a result, operators can avoid problems often associated with hydraulic fracturing and acidising where fractures can grow vertically into neighbouring water zones. There are hundreds of cases where propellant tools have been the only stimulation solution an operator has in wells with close water contacts.

Injection wells
Injection wells have historically been one of the most successful applications for propellant stimulation tools. Regardless of whether the injection well is used for a waterflood or waste disposal, performance can be significantly enhanced by this technology.

Over time injection wells often become damaged by the fluids being injected into the reservoir. This increases injection pressure requirements and reduces the amount of flow. Injection pressures can rise to the point where an operator can no longer inject fluids at all because of mandated pressure limits. A stimulation becomes necessary in order to break past the damage and restore flow. Because the damage is often restricted to the nearbore region of a well, a propellant stimulation is typically all that is needed to reduce pressures and improve injection rates.

Close water contacts
When designed properly, propellant tools create multiple radial fractures extending from the wellbore. This fracture pattern is illustrated above the GasGun heading in Figure 2. This provides superior nearbore permeability. These multiple fractures are created in a matter of milliseconds, which allows the vertical growth of the fractures to be controlled. As a result, operators can avoid problems often associated with hydraulic fracturing and acidising where fractures can grow vertically into neighbouring water zones. There are hundreds of cases where propellant tools have been the only stimulation solution an operator has in wells with close water contacts.

Cement invasion
Another very common application for the GasGun is for wells that have formation damage as a result of cement invasion. This commonly occurs after cement squeeze jobs or when setting casing during the initial completion of a well. Many operators will simply perforate the well to try and establish communication with the reservoir. Many times this is unsuccessful because the perforations are not able to penetrate deep enough into the formation to bypass the damage, and as a result the well will need to be stimulated. Hydraulic fracturing is commonly chosen, but this is a very costly method of removing nearbore damage. Acidising is another option, but it can be difficult to control and can channel out of the pay zone. Propellant stimulations are a very efficient way to remove this type of formation damage because they are focused in the pay zone and can reach tens of feet past the perforation tunnels. In most cases this is all that is necessary to restore communication with the reservoir.

Pre-frac treatment
In some wells, propellant stimulation tools are used in advance of a hydraulic fracturing treatment. Some reservoirs can be very difficult to break down during hydraulic fracturing. This can further be exacerbated by the fact that perforators crush and compact rock, which leads to the creation of skin in the perforation tunnels. As a result, breakdown pressures can exceed the capabilities of the downhole and surface equipment. It can also lead to premature screenouts in the wellbore. A very simple and economical solution to this problem is to shoot a propellant tool in advance of the hydraulic fracture. In some situations this can be the difference between running a successful fracture treatment or none at all.

Another reason for running a propellant tool prior to a hydraulic fracture is to preferentially break down certain sections of a reservoir. When fracturing long perforated intervals it can be difficult to get all the perforations stimulated effectively. Using a propellant tool in sections that are known to be more difficult to break down will allow for a more homogeneous stimulation of the entire reservoir.
Developing applications

As the GasGun has gained acceptance by larger oil and gas companies with more sophisticated completions, the technology has found new uses for these applications. These newer applications include formation evaluation, gas storage wells, and remote locations. While these applications represent a relatively small portion of the total propellant stimulations performed, they are growing in popularity.

Formation evaluation

Formation evaluation has become increasingly important to operators trying to optimize their fracturing programs. Obtaining accurate production test results from each proposed reservoir gives the completions engineer the information they need to evaluate the potential of each zone and design the frac job accordingly. In order to achieve accurate data, it is critical that operators are well connected to the reservoir. Many operators achieve this by pumping into the formation to break down the perforation tunnel damage. This works well in many cases, but it can be time-consuming, expensive, and detrimental to formations that are water sensitive. Running a propellant tool instead of pumping provides similar benefits, but often at a reduced cost and it is compatible with all formation types.

**Case One** - A large independent operator with a field in West Texas has a very active drilling program with several new well completions each week. The target formation is a sandstone with several intervals ranging from 4000-6000 ft deep. These are all gas wells, and they require significant fracturing in order to be commercially viable. The operator completes each stage by running a conventional hydraulic fracture treatment with a mixture of different sands for proppant. It had been experiencing difficulties with the flowback of each stage because the reservoir would not give back the injected fluid. The result was suboptimal gas production.

The operator wanted to experiment with running CO2 fracture stimulations to try and eliminate the flowback problems. Each zone would need to be individually production tested prior to stimulation. The operator did not want to run the risk of pumping into each zone with water to break the perforations down for fear that it would further damage the water sensitive formation. It decided to use the GasGun to get past all the nearbore damage and establish good connectivity with the reservoir.

The operator was able to test, stimulate, and flowback each zone successfully. For several months after the stimulation, the well performed better than neighboring wells that had been conventionally fractured. As a result, the operator revamped its fracturing program and continued to use the tool to evaluate its reservoirs prior to stimulation.

**Case Two** - A large independent operator with a significant acreage position in the Marcellus Shale drilled some vertical test wells in the field so that it could monitor the pressure in the reservoir over time. It wanted to ensure that the well completion left as little skin as possible in order to get precise measurements of virgin reservoir pressure. After perforating the shale, it monitored pressure for several weeks and knew fairly quickly that it did not have good connectivity with the reservoir.

The operator assumed that there must be skin damage in the perforation tunnels. It considered pumping into the formation with fluid, but was concerned that it would skew the pressure measurements because it would artificially charge the reservoir. It decided to reperforate using reactive shape charges, which are designed to break up and remove debris in the perforation tunnels leaving as little skin as possible. Unfortunately, after this reperforation effort, it did not see any change in the reservoir pressure and believed that there must still be some damage further out from the wellbore.

The operator then decided to stimulate the formation using the GasGun in order to bypass the damage. The day after the stimulation, it ran pressure gauges again and found that it now had the connectivity it was looking for. At the date of writing, the operator has been monitoring the reservoir for six months and continues to get unobstructed pressure measurements. The operator has since shot another test well with the GasGun in a different part of the field and experienced the same positive response.
Gas storage wells

As discussed earlier, injection wells are typically one of the best applications for propellant stimulation technology. While gas storage wells are not injection wells in the classic sense, it is important to maintain their deliverability, which means keeping the formation damage to a minimum. Good communication with the reservoir allows a gas storage well operator to inject and withdraw with optimal efficiency.

Case one - A gas storage well operator in the Northeastern US was experiencing problems with injection and withdrawal of gas in several of its wells. It was believed that the formation had been damaged by the repeated injection and withdrawal cycle over several years.

Hydraulic fracturing was cost prohibitive so the operator decided to test the GasGun in three gas storage wells. Two of these wells were cased hole completions and the third was open hole. It shot 20 ft of zone in each of the three wells and then put them back into the injection cycle.

The operator was pleased with the initial results from the stimulation, but more time is needed to properly evaluate the injection and withdrawal rates.

Remote locations

The use of propellant stimulation tools in very remote locations is not a common occurrence, but when it does occur it really highlights the ease and efficiency of this type of stimulation. Hydraulic fracturing requires so much equipment that it can either be too expensive or simply impossible to conduct in a remote area.

Case one - The town of Wainwright is a Native community of approximately 500 residents in Northwest Alaska. A picture of the town can be seen in Figure 3. The only means of power generation in this small town is to transport approximately 500,000 gal./y of diesel by barge. The burning of diesel fuel for power generation represents a significant expense and sense of dependence for this small community.

In June 2007, in a co-operative effort among the US Geological Survey, Bureau of Land Management, Arctic Slope Regional Cooperation, North Slope Borough, and the Olgoonik Corporation a 1600 ft continuous core hole was drilled and tested to determine if coalbeds that underlie the community contain sufficient methane to serve as a viable and economic alternative energy source. A picture of the drilling rig can be seen in Figure 4.

Initial results from the well indicated that enough methane gas was present in the subpermafrost coal seams to serve as a power source for this small community. It was also determined that methane could be produced without the need for extensive reservoir stimulation.

After several more years of testing and somewhat disappointing long term production results, it was decided that the test well was in need of some form of stimulation. Due to the remote location of the well and equipment constraints the GasGun proved to be the most viable solution to its stimulation needs.

In May 2010, a 6 ft GasGun was air freighted to the town of Wainwright. In late June the GasGun was shot from a skid mounted wireline unit. After several weeks a gravel pack was installed and the well was production tested. After the treatment the well dewatering rates doubled and gas production has been increasing steadily.

Conclusion

Propellant stimulation tools represent a growing and important part of the overall oil and gas well stimulation market. They provide an economical alternative to other forms of stimulation and in some cases they represent the only solution to an operator’s stimulation needs. They have garnered the acceptance of the smallest of operators with just a few wells to the largest of the independents. With the ever growing list of applications, propellant tools will continue to be a viable stimulation option for oil and gas companies in the future.
Propellant stimulation tools have been used to fracture oil and gas wells for over 50 years. A variety of different propellant formulations including rocket fuel, potassium perchlorate, and progressively burning propellants have been used during that period with varying success. Progressively burning propellants have a unique burning characteristic in which the rate that the propellant burns increases with time, producing gas in increasing volume as the material is consumed. These propellants were proven by independent research conducted by Sandia National Laboratories to be many times more effective in creating fractures and increasing formation permeability.

A progressive burn is achieved with the use of a multi-perforated propellant grain. Other propellant designs typically have a solid configuration resulting in a regressive burn where the surface area decreases as the material is consumed. The design of the GasGun is based on the use of progressively burning propellants.

The GasGun is a solid propellant fracturing device based on ballistic technology from the US military. The propellant generates high-pressure gases at an accelerating rate that create a fracturing behaviour dramatically different to either hydraulic fracturing or explosives. The ability to produce these fractures in order to bypass near wellbore damage has been demonstrated experimentally and verified through extensive field applications.

The development of modelling software specific to GasGun progressively burning propellants is ongoing and incorporates a wide range of data including wellbore configuration, rock properties (Poisson’s ratio, Young’s modulus, fracture toughness, tensile strength, etc.), state of stress (pore pressure, overburden stress, horizontal stresses, etc.) and concentration stress around the wellbore. It will also include flow modelling that characterises the bubble/gas flow inside the fractures and will model the gas loss through fracture faces into the formation. Post frack test data is then used to calibrate the model, particularly as it pertains to applications in the same field, formation and basin.

Maximising production
Many companies in the oil and gas sector have been dedicated to maximising the production from reservoirs with near wellbore damage. Very sophisticated and expensive muds and kill fluids, acids, chemical washes and fracking have been used to either avoid
damaging the formation in the first place or to reduce the impact of the flow restriction that near wellbore damage can cause in the event the preventative measures fail. The viscosity of the long chain hydrocarbons that characterise heavy oils exacerbates the choking effect. The correct application of progressively burning propellants has been proven to bypass near wellbore damage, increasing the effective permeability, the ‘KH’ of the interval. This can be achieved through the application of the technology associated with progressively burning propellants without the negative effects associated with chemical treatments or in the case of fracking, the high cost and the risk that a vertical fracture may communicate with other zones, perhaps water or gas bearing. This technology has the potential to add significant production and thus increase revenue very cost-effectively if applied to address the specific problems associated with near wellbore damage.

**Statement of theory and definitions**

A progressively burning propellant burns and generates gas at an increasing rate by virtue of its design. As it burns, more surface area is exposed, which accelerates the rate at which gas is produced as the propellant is consumed.

The idea for a progressively burning propellant originated long before the technology was applied in the oil industry and, as is the case for many new technologies, it was driven by the military who wanted to launch their shells much further than allowed by the traditional gunpowder charge utilised in the naval and land battles of the 19th Century. Basically, if a shell is to be accelerated up a long barrel using a propellant, it is essential that high-pressure gas be generated faster and faster to fill the rapidly increasing volume in the barrel behind the shell and to accelerate the shell. This concept is not very different to what it takes to propagate fractures originating in a wellbore in that after the fracture is initiated, increasing volumes of gas are required to ensure the fracture continues to propagate and thus bypass near wellbore damage or intercept a natural fracture system.

Practical benefits from the correct application of the technology can include the following:

- Creation of multiple radial fractures originating in open holes, perforation tunnels or slotted liners. Fractures in excess of 25 ft were observed in the Sandia tests.
- Bypassing of near wellbore damage caused by drilling mud, completion fluids, cement, fines, scale, or other chemical deposition leading to significant improvements in effective KH.
- Increase in production from naturally fractured reservoirs by intercepting more fractures.
- Reduction in costs of traditional fracking by reducing pressure and hydraulic horsepower requirements.
- Improved effectiveness of acidising by allowing more of the reservoir to be contacted.
- Increased injection rates in waterfloods, waste disposal, and gas storage wells.
- Reduced risk of communicating with other zones as 98.5% of energy is focused to the targeted reservoir. Vertical fracture growth out of the zone of interest is minimal which is often a major downside to conventional fracking. To illustrate why the energy is contained to the zone of interest, the following calculation is presented:

**Movement of water column above GasGun stimulation.**

\[
P = 20,000 \text{ psi} \\
L = 1000 \text{ ft} \\
A = 0.213 \text{ ft}^3 \text{ (6 1/4 in. open hole)}
\]

\[
a = F/m = PAg/W = PAg/ALp = Pg/Lp
\]

**Distance water column moves in 20 msec is:** \[s = \frac{1}{2} at^2\]

In this example, the water movement is 0.04 m, implying that the energy should have been kept well within the chosen interval.

**Data and observations**

Independent research performed by Sandia National Laboratories in the 1970s was conducted in a tunnel complex at the Nevada Test Site, and...
direct observations of the fractures created by various propellant tools were made by mining out the boreholes after stimulation. The Stressfrac tool was one of the propellant fracturing technologies tested by Sandia. Its design was based on the use of propellant with regressive burning characteristics similar to that of many other propellant tools currently available. While the initial burning creates high pressures and does in fact generate multiple fractures, the regressive burning characteristics do not allow for significant propagation of those fractures because gas generation is decreasing while fracture volume is increasing. Fractures that were mined out were less than a foot in length, which limits the ability of the tool to bypass near wellbore damage and to significantly increase flow rates (Figure 2). The direct observations made by the researchers at Sandia demonstrated that progressively burning propellants produce a much more extensive multiple fracture pattern. The created fractures extended more than 25 ft from the wellbore. The longer fractures are a result of the increasing gas volumes produced over time from progressively burning propellants while at the same time fracture volume is also growing. This improved fracturing occurs while limiting peak pressures in the borehole and thus reduces the chances of damage to downhole equipment that is often associated with other types of propellant tools (Figure 3).

The fracture patterns were mapped out by the onsite geologist at Sandia to more clearly demonstrate the multiple fractures that were created (Figure 4).

Results
Ecopetrol ran the GasGun in a number of wells in various basins and producing horizons throughout Colombia. Pressure data indicated the presence of significant near wellbore skin in some wells. Other wells were inferred to have significant damage based on the behaviour of adjacent wells with similar petrophysical characteristics. Table 1 summarises the results in these initial wells.

Castilla is a very large heavy oil accumulation located in the Llanos Basin of Colombia. Discovered by Chevron in 1969, Ecopetrol assumed responsibility for the operation of the field in 2002 and since that time has built production to over 100 000 bpd. The main producing stratigraphic units are the Massive Guadalupe, or K2, and Upper Guadalupe, or K1. The K2 is a sand dominated system deposited in braided and meandering channels. The deposits are primarily gravels and sandstones, generally poorly sorted, fine to medium grained. The K1 Inferior unit consists of coastal plain sandstones and mudstones. The K1 Superior is predominantly a shale and siltstone interval. Several initial wells in Castilla were chosen based on the presence of significant skin damage inferred from pressure build up analyses. These initial results are outlined in Table 2.

Conclusion
The GasGun was able to cost-effectively increase production in a wide range of wells in various basins and reservoirs with the specific results depending on the degree to which the effective permeability was impaired by near wellbore damage and thus had positive skin factors. Ideally, the decision to employ the technology outlined in this discussion would be based on pressure build up analysis. However, this is not possible or is cost-prohibitive in many wells. Hence the decision can be based on poor well performance where petrophysical evidence suggests the presence of significant damage.
GasGun® Stimulation vs. Traditional Stage Frac

In December 2005, a major Canadian producer decided to test the GasGun against traditional stage fracs in twelve shallow gas wells of the Basal Belly River formation in Alberta, Canada. They stimulated six wells with the GasGun and six with 5 tonne sand fracs. The operator then conducted a pressure transient analysis on each well. Results of this analysis show the calculated parameters to be remarkably similar between these two methods and that the effectiveness of the stimulations to be roughly equivalent. The producer chose the GasGun over hydraulic fracturing for the rest of the field because it is considerably less expensive.

<table>
<thead>
<tr>
<th>GasGun</th>
<th>BHP (kPa)</th>
<th>Skin Factor</th>
<th>XF (m)</th>
<th>eff. K (mD)</th>
<th>kH (mD.m)</th>
<th>Production (MCF/D)</th>
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<tr>
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<th>XF (m)</th>
<th>eff. K (mD)</th>
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<td>5.92</td>
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* Averages for GasGun data excludes Well #1 on the basis of it being anomalous when compared with the others

Xf is fracture half length in meters  
Eff K is the effective permeability in millidarcies  
kH is the perm from the PTA results multiplied by the height of the pay zone
Operator in Ecuador Uses GasGun to Enhance Production from Existing Completion

BACKGROUND
In April 2017 an operator in Ecuador used the GasGun to stimulate production from a sandstone reservoir. The well is located in the TAPI field which is in the northeast portion of Ecuador bordering Colombia. The well was drilled and completed in August 2014 to a measured depth of 10,019 feet. The operator completed the well with 7” production casing and perforated two sandstone reservoirs; the Arena “Ti” and Arena “Ui”.

The well had initial oil production of over 1000 BOPD. Oil production declined rapidly over the next few years. Several workovers were performed to improve production with various levels of success. Combined oil production from the reservoirs dropped from 252 BOPD to 80 BOPD in 2017. The operator decided another workover was needed and this time they wanted to stimulate the reservoir with the GasGun.

SOLUTION
Pre-job modeling was performed to select the proper GasGun tool for use in this application and estimate the performance of the stimulation on the reservoir. Based on the modeling it was decided that the 4” OD GasGun was best suited for this application. The operator selected to stimulate just the lower Arena “Ti” sandstone for stimulation. The GasGun tool string was then designed for the job by the local service company.

Based on the data provided by the client including production history, logs, and geomechanical properties of the reservoir an estimate of the performance of the stimulation was generated. This estimate included the number of fractures and fracture lengths generated by the GasGun. It also included the anticipated PI improvement and an IPR curve. The pre-job modeling predicted the well would respond favorably to the stimulation so the client decided to proceed with the stimulation.

Prior to the GasGun stimulation the well was producing 134 BPD of fluid with 40% BSW (80 oil & 54 water) at 700psi intake pressure. After stimulation the well produced 264 BPD with 50% BSW (132 oil & 132 water) at 650psi. High gas production after the stimulation lowered the efficiency of the electric pump. Once gas production is stabilized the operator believe production will improve even further.

Nearbore Damage
- Remove skin from perforators, drilling, cement, etc.
- Fractures created at every perforation tunnel
- Improve effectiveness of acidizing

www.TheGasGun.com
**COMPAÑÍA:** PETROAMAZONAS  
**POZO:** TAPI-11D  
**RIG:**  
**FECHA:** Marzo 6, 2017  
**ESPECIALISTA:** VIRGILIO LEON SANCHEZ  
**COMPETAMIENTO:** CCL - GASGUN SHOOTING  
**UNIDAD DE MEDIDA:** PIES  

### GR-CCL SHOOTING - GASGUN RUN

<table>
<thead>
<tr>
<th>RUN No.</th>
<th>TOP</th>
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<th>SPACER</th>
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<td>0</td>
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<td>2</td>
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<td>9900</td>
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<td>3</td>
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<td>9882</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>24</strong></td>
<td><strong>6</strong></td>
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**PRE-ESTIMATED FOR TAPI -11D ARENA T1**

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>Number of Radial Fractures</th>
<th>Fracture Lengths (ft)</th>
<th>PI IMPROVEMENT Jafter/Jbefore</th>
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<tr>
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<tr>
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<td>25</td>
<td>1.3</td>
</tr>
<tr>
<td>LOWER</td>
<td>5</td>
<td>22</td>
<td>1.22</td>
</tr>
</tbody>
</table>
EMR = 912.30'
ES = 881.30'
MR = 31'

563' MD / 5293' TVD

MAXIMO ANGULO 26.1°
@ 3432' MD / 3259' TVD

Bajan flat cable #2, empaque de cable a 4300' y 9200'. Bajan con capilar exterior: 1 capilar de 1/4" desde el sensor hasta la descarga de presión; el segundo de 1/4" desde el centrificador hasta superficie. Instalan con 69 bandas en equipo BES, 7 bandas en bha y 10 en tubería, 294 Protectores Canon y 295 Mid Joint. Peso de la sarta 130 Klbs/up, 96 Klbs/down.

9-5/8" x 7" COLGADOR LINER

ARENA "UI"
9740’ - 9750’ (10') a 10 DPP WO-01
9762’ - 9772’ (10') a 10 DPP WO-01

ARENA "TI"
9876-9882 (6') a 5 DPP WO-02
9892-9910 (18') a 5 DPP WO-02
INFLOW PERFORMANCE RELATIONSHIP
TAPI-XXX
Arena 11  9892’ - 9910’ (18’) - 9876’ -9882’ (6’) 5 SPF

WorseCase
MediumCase
HighCase
Actual
Nearbore Damage

- Remove skin from perforators, drilling, cement, etc.
- Fractures created at every perforation tunnel
- Improve effectiveness of acidizing

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Operators and engineers have used the GasGun to effectively bypass cement invasion, scale, mud cake, damage from perforators, skin and other forms of nearbore damage since it was commercialized in the early 1990’s. The GasGun is a unique tool that is tailored to create multiple radial fractures producing optimum nearbore drainage. The fractures generated with the GasGun reach 10 – 50 feet horizontally into the formation with very little vertical fracture growth. The multiple fracture network created nearbore makes it a great tool for cleaning up nearbore damage and beyond.

Case Study
Application: Nearbore Damage (New Zone)
Formation: Wolfbone (sandstone)
Depth: 10,506’
County: Reeves
State: Texas

In June of 2012 an operator in Reeves County chose to perforate and shoot GasGuns to stimulate the Wolfbone formation @ 10,506’. The Wolfbone reservoir of West Texas consists of complex, low-porosity sequences of sand, shale, and carbonate layers which typically needs to be stimulated to be commercial. When the service provider ran the perforating guns out of the hole after the shot there was black water in and on the perforating equipment but no signs of oil. After swabbing the well had no oil. The service provider then ran the GasGun over the same interval. Once the GasGuns were fired and brought out of the well they were covered in “Lime green oil” according to both the operator and the service provider. Later swabbing and production showed that the GasGun was able to stimulate the zone and connect the wellbore.
with the desired productive zone with good result. The specific production data itself was asked to be kept proprietary by the operator but they have since completed more wells using the GasGun for stimulation.

*At these depths perforating charges do not have the same penetration as they do at shallower depths. This is caused by the additional earth stress in deep environments and compressed hard rocks that are encountered at these depths. Very often simply perforating can fail to get well connected to the reservoir. This effect is often exacerbated by nearbore damage including cement invasion. The fractures created by the GasGun are shorter in deeper applications due to those same stress principles but have the power to penetrate much further out than the perforating charge and will allow an operator to fracture into the reservoir and connect with the hydrocarbon rich formation. GasGun fracture penetration @ 2,000' can be up to 50’ while fracture lengths in wells of 10,000’ will be closer to 10’-15’ in penetration.

![Close Water Contact](image)

**Close Water Contact**

- Minimal vertical fracture growth
- Improve effectiveness spotting acid
- Fractures stay in pay zone

Many oil & gas producing formations are located in close proximity to water bearing zones. For example the Arbuckle dolomite in Kansas (USA) is a natural waterdrive reservoir where production is controlled by large void space features like fractures, vugs and/or other ultra-high permeability rock. Traditional frac & acid frac stimulation methods pressure the formation to fracture and will commonly break into the prevalent water bearing zone below, creating detrimental production problems.

The GasGun propellant stimulation tools create multiple radial fractures (like slices in a cake) that penetrate horizontally into the formation on the order of 10’-50’ depending on depth and rock properties. Vertical fracture growth of a GasGun stimulation is restricted to 1’-3’ above and below the tool, giving the operator unprecedented control in the placement of fractures in close water contact applications. The nature of fracture propagation was studied at Sandia National Laboratories (SPE8934) whereby physically mining back the fracture network provided invaluable information about the exact performance of the GasGun and other propellant tools.

---

**The GasGun, Inc.**

15927 SE 122nd Ave  Clackamas, OR 97015

Phone: (877) 557-1370  www.TheGasGun.com
After learning about the nature of the fractures created by the GasGun, operators quickly learned that they could effectively soak acid in the newly created fracture network with great result. Thus the GasGun can be a great tool for operators stimulating production zones that lie near water bearing formations.

For over a decade operators in close water contact applications have utilized GasGun tools to accurately fracture pay zones without breaking into water bearing zones nearby. These fracturing characteristics specific to the GasGun are a product of the speed of the event (pressure-time profile) and the fact that the event is taking place in an incompressible fluid filled environment which tamps the charge to the formation.

**Case Study**

**Application:** Nearbore Damage & Close Water Contact  
**Formation:** Arbuckle Dolomite  
**Formation Depth:** NA  
**Prior Production:** None (new well)  
**After Stimulation:** 12 BOPD

A new well in Ellsworth County, Kansas, was stimulated with a 6 foot GasGun. This well is a cased hole completion in the Arbuckle dolomite formation. The operator completed the well by perforating the casing and the well had no production. The operator tried to do a 500 gallon acid treatment in an attempt to bring in some production. They couldn’t get the formation to take the acid which led them to believe there was nearbore damage present which was not allowing the acid to flow into the formation. They then went ahead and shot the zone with the GasGun to bypass the nearbore damage without breaking into the water bearing zone below. After the GasGun, the operator was able to get the acid into the formation and production came in at 12 BOPD.
Application: Production Gas Well
Depth: 8270'
Formation: Gulf Coast Sand
Location: Offshore LA, USA
Before GG: No Production at all
After GG: 5.289 MMCF, 8 BCPD, 7 BWPD, 1600 psi ftp on 20/64 choke

In February of 2015 an operator in Louisiana shot a vertical well with a 2” thru tubing GasGun in a gulf coast sandstone formation. Prior to the GasGun, the operator had tried perforating in two separate attempts to establish connectivity to the permeable sandstone formation. After perforating the operator attempted to pressure up on the zone to 2500 psi to test leakoff into the zone. The zone would not take any fluid.

After treating the zone with GasGun the operator was able to pressure up to 2000 psi and the formation accepted fluid rapidly. Once placed on pump the well settled out at 5.289 MMCF, 8 BCPD, 7 BWPD, 1600 psi ftp on 20/64 choke. This was a clear case where the 2” OD GasGun was able to fracture out past the nearbore damage and cement invasion that was impeding flow to the wellbore.

Nearbore Damage
- Remove skin from perforators, drilling, cement, etc.
- Improve effectiveness of acidizing
- Fractures created at every perforation tunnel

Nearbore Damage is any restriction to flow caused by near-well reductions in flow capacity. This damage can be caused by perforators, drilling mud, cement invasion, scale, etc. Nearbore Damage not only limits production but inhibits you from gathering accurate data about your completed zones. Bypassing Nearbore Damage is vital for proper decision making and ultimately the overall productivity of your well (ROI).

Operators and engineers have used the GasGun to effectively bypass cement invasion, scale, mud cake, damage from perforators, skin and other forms of nearbore damage since it was commercialized in the early 1990's. The GasGun is a unique tool that is tailored to create multiple radial fractures producing optimum nearbore drainage. The fractures generated with the GasGun reach 10 – 50 feet horizontally into the formation with very little vertical fracture growth. The multiple fracture network created nearbore makes it a great tool for cleaning up nearbore damage and beyond.
Application: Injection Well
Depth: 7769’
Formation: Esmeraldas La Paz (sandstone)
Country: Colombia
Before GG: 1500 BWPD @ 3500 psi
After GG: 4500 BWPD @ 3500 psi

In May of 2015 Ecopetrol, the state owned oil company of Colombia shot a vertical injection well with 68 total feet of GasGun in the Esmeraldas La Paz formation. After treating the zone with GasGun the operator circulated the well back to allow scale and debris from the wellbore to be removed prior to injection cycle. Before the treatment the well would only accept 1500 BWPD @ 3500 psi. The GasGun was able to fracture the zone to allow for an injection rate 3X the rate at which they could previously inject at the same pressure.

Injection Well

- Increase injection and withdrawal rates
- Bypass nearbore damage
- Provide a homogenous injection profile
- Reduce injection pressures

Over time many injection wells develop restrictions to flow and need to increase treating pressures in order to continue injecting fluid. Many states restrict injection pressures to keep them under the pressure required to fracture the reservoir. If an injection well will not accept fluids below this mandated pressure limit the operator must find a way to reduce treating pressure or risk having the well shut down.

Contributing factors to reduced flow can come from the source water itself. Injected fluids used can come from many sources such as produced water, seawater, aquifer, river, etc. Each type will contain different types of solids, bacteria, oxygen, as well as dissolved minerals. Even after treating the source water, over time the fluid can block pores in the rock and form wellbore skin hindering the reservoir’s ability to inject.

Whether by state law or to simply improve well performance, operators have turned to the GasGun to lower injection pressures and increase injection rates. The GasGun is positioned over the injection zone and when fired it creates multiple radial fractures, exposing fresh rock and fracture flow-paths for injector fluids. This increase in permeability reduces injection pressures and has on many occasions made the zone take fluid on vacuum.
Application: Stimulation (New Zone)
Depth: 10,506'
Formation: Wolfbone (sandstone)
County: Reeves
State: Texas

In June of 2012 an operator in Reeves County chose to perforate and shoot GasGuns to stimulate the Wolfbone formation @ 10,506’. The Wolfbone reservoir of West Texas consists of complex, low-porosity (4-10%)/low permeability (nanodarcy to millidarcy) sequences of sand, shale, and carbonate layers which typically needs to be stimulated to be commercial. When the service provider ran the perforating guns out of the hole after the shot there was black water in and on the perforating equipment but no signs of oil. After swabbing the well had no oil. The service provider then ran the GasGun over the same interval. Once the GasGuns were fired and brought out of the well they were covered in “Lime green oil” according to both the operator and the service provider. Later swabbing and production showed that the GasGun was able to stimulate the zone and connect the wellbore with the desired productive zone with good result. The specific production data itself was asked to be kept proprietary by the operator but they have since completed more wells using the GasGun for stimulation.

*At these depths perforating charges do not have the same penetration as they do at shallower depths. This is caused by the additional earth stress in deep environments and compressed hard rocks that are encountered at these depths. Very often simply perforating can fail to get well connected to the reservoir. This effect is often exacerbated by nearbore damage including cement invasion. The fractures created by the GasGun are shorter in deeper applications due to those same stress principles but have the power to penetrate much further out than the perforating charge and will allow an operator to fracture into the reservoir and connect with the hydrocarbon rich formation. GasGun fracture penetration @ 2,000’ can be up to 50’ while fracture lengths in wells of 10,000’ will be closer to 10’ in penetration.

Nearbore Damage

- Remove skin from perforators, drilling, cement, etc.
- Fractures created at every perforation tunnel
- Improve effectiveness of acidizing
Application: Stimulation (New Zone)
Depth: 10450'
Formation: Tuscaloosa sand
County: Jones
State: MS

In July and August of 2011 Petro Harvester targeted the Tuscaloosa in two different wells in Jones Count, Mississippi. The Tuscaloosa formation is primarily composed of chert gravel, sand, and clay lithologies equivalent to the western lithofacies. Average porosity is 22%, but frequently tops 28%; permeability ranges from nil in very tight siltstones to well over two darcies in the best reservoir rocks. The wells were 10,450’ and 10,770’ respectively and both we new completions in the Tuscaloosa. After perforating and running the GasGun they were able to successfully connect to the reservoir in both cases making wells that produced significantly higher than their non-GasGun treated offsets. The first well came in producing 120 BOPD while the other a distance away contributed 50 BOPD. Typical offset wells produce naturally at rates averaging 20-30 BOPD. This company has continued to be a repeat customer, treating more wells in this field as well as the Rodessa formation, a shallower productive zone in the area.

*The significant clay content of the Tuscaloosa Sand reservoirs makes them much more sensitive to drilling and completion fluids, as well as acid and fracture stimulation treatments; for example, common hydrochloric acid attacks the chlorite platelets, causing partial platelet dissolution and the formation of a gel-like substance that dramatically reduces near-wellbore permeability. For this reason, treating the zone with the GasGun allows the operator to create the desired fracture network without introducing foreign fluids that can cause the formation of skin, which would reduce valuable permeability.

Fluid Sensitive Formation
- No introduction of foreign fluids
- Mechanically fractures formation without the need for water & chemicals
An operator in Alberta, Canada, wanted to increase the injectivity index for a disposal well, as the wellhead pressure had become too high to achieve the required injection rate. The well in question was a vertical well with barefoot completion and a total depth of 1749 ft. (533 m). It was completed in the McMurray formation, an unconsolidated sandstone, and had a gravel pack with 5-inch diameter wire-wrapped screen.

The operator indicated that the well suffered from nearbore damage and had tried to resolve the problem with acid, but this had no effect.

In April of 2013 the well was stimulated with eleven 3 3/8-inch diameter by 10-foot long GasGun tools. The operation was performed rigless with a wireline truck that included a portable mast.

After stimulation the operator noted an increase in the injectivity index making their disposal well 35% more efficient. The increased efficiency meant that they could continue to use low pressure wellheads and allowed them to achieve the required disposal capacity without having to drill additional wells. The operation was conducted in a similar time frame to alternative solutions, but at a cost savings of $250,000 USD.

Injection / Disposal Well

- Increase injection rates
- Bypass nearbore damage
- Provide a homogenous injection profile
- Reduce injection pressures
GasGun Pre-Frac Applications

Problem:
Sept. 2011 Red River Petroleum attempted to frac the Kunc #A-4. During the frac operation they pressured up to maximum pressure from surface and were not able to break down the formation.

Solution:
On 09/06/11 Red River Petroleum shot a 10 foot GasGun in the zone to break it down.

- Reduce tortuosity and resulting screen-outs
- Break down formation/ reduce treating pressures
- Create fractures in preferred plane

*The GasGun creates a radial fracture network which breaks down the formation, increases near wellbore permeability, and reduces tortuosity. The fractures penetrate 10 – 50 feet into the formation and subsequent frac jobs will typically have lower breakdown pressures. The improved flow-path characteristics enhance the performance of pump-in, flow-back, and final production.

Outcome:
The operator returned after the GasGun treatment and attempted to frac the zone with the same equipment. The formation "broke down easily" according to the operator Derek and they "made a well out of it".
GasGun Pre-Frac Applications

On 1/11/11 well FCS #323 was drilled in Stone Wall County Texas. The targeted zone was the Canyon Sandstone at a depth of 4291’. The operator had previously been running standalone hydraulic fracture treatments. Breakdown pressures on those hydraulic frac jobs were 1800 – 2,000 psi. After shooting the GasGun to break down the formation and reduce tortuosity the subsequent frac job broke at 900 psi surface pressure, which is significantly lower than normal (usually 1,800 to 2,000 psi) and the surface treating pressure was lower than normal throughout the frac job. This allowed for less horsepower on site and a more effective overall fracture treatment.

![Pre-Frac GasGun Results](chart.png)
Application: Heavy Oil (9 API)
Depth: 6809'
Formation: Xmas A (sandstone)
County: Perry
State: Mississippi

In July of 2014 an operator in Perry County chose to perforate and shoot GasGuns to stimulate the Xmas A formation @ 6,809'. This is a highly deviated well (80 degrees) completed in the Xmas A which is part of the Tuscaloosa sandstone formation. The Tuscaloosa formation is primarily composed of chert gravel, sand, and clay lithologies equivalent to the western lithofacies. Average porosity is 22%, but frequently tops 28%; permeability ranges from nil in very tight siltstones to well over two darcies in the best reservoir rocks. This well produces very heavy 9 degree API oil and had production prior to the GasGun of 33 BOPD & 2050 BWPD. After shooting the GasGun swab testing produced 225 BOPD with long term production leveling off at 55 BOPD.

After this well was stimulated with the GasGun and tested, the company decided to continue stimulating more wells in this field with GasGun. The next well that was treated showed similar positive results.

**Heavy Oil**

- Remove skin from perforators, drilling, cement, etc.
- Fractures created at every perforation tunnel
- Improve effectiveness of acidizing
Application: Heavy oil
Depth: N/A
Formation: Lloydminster
Country: Canada
State: Alberta

The Lloydminster heavy oil field is predominantly made up of deltaic sands of the Lower Cretaceous Mannville Group. Throughout 2013 & 2014 CNRL (Canadian Natural Resources Limited) has continued to use the GasGun to stimulate ~50 wells in their heavy crude oil assets. Originally they decided to try GasGun on existing wells which resulted in extending the economic live of the well 6 months further after paying for the treatment. Management evaluated the results from the mature wells and decided to implement GasGun on newly drilled wells which would allow the wells to benefit from the increased flow paths (created by the GasGun) over the life of the well. Success rate on extending the economic life of their wells has been 100%.

Heavy Oil

- Remove skin from perforators, drilling, cement, etc.
- Fractures created at every perforation tunnel
- Improve effectiveness of acidizing
Nearbore Damage

- Remove skin from perforators, drilling, cement, etc.
- Fractures created at every perforation tunnel
- Improve effectiveness of acidizing

Application: Nearbore Damage/Cement Packer (Thru-Tubing)
Depth: 8270’ - 8344’
Formation: Amph E-2a Sandstone
County: Offshore
State: Texas

Nearbore Damage is any restriction to flow caused by near-well reductions in flow capacity. This damage can be caused by perforators, drilling mud, cement invasion, scale, etc. Nearbore Damage not only limits production but inhibits you from gathering accurate data about your completed zones. Bypassing Nearbore Damage is vital for proper decision making and ultimately the overall productivity of your well (ROI).

Completion: January of 2015 an operator approached us to remedy a well they had recently completed. This was an offshore well completed in a Gulf Sandstone which had been completed with a cement packer between 2 7/8” tubing and 7 5/8” casing. (See WBD below)

Perforating: Initially a hollow carrier was shot 12 spf and after not getting feed-in and not being able to pump in with 2,500 psi the operator then decided to add additional perforation over the interval @ an additional 6 spf using the strip gun. The 2.125” Shogun NTX Raptor, 6spf (13.9 Gram Charges) 60 Deg strip gun from Owen had perforator analysis report resulted in the penetration table displayed below:
Problem: After perforating the operator was still unable to establish communication to the reservoir due to nearbore damage and the inability of thru-tubing perforator charges to effectively penetrate through 2 7/8” tubing, cement, 7 5/8” casing, cement and into the formation. “We are unable to pump into the well and are not getting any feed-in during pressure build up.”-Operator

Solution: 2” Thru-tubing GasGun (Product page below). The 2” GasGun system can be run on wireline and is designed to fit through 2 7/8” tubing. After locating the tools over the perforated interval the tool is fired and rapidly builds pressure in the wellbore. The pressure is forced out the perforation tunnels creating fractures out each perforation tunnel and into the formation. Operators and engineers have used the GasGun to effectively bypass cement invasion, scale, mud cake, damage from perforators, skin and other forms of nearbore damage in thousands of wells. The GasGun is a unique tool that is tailored to create multiple radial fractures producing optimum nearbore drainage. The fractures generated with the 2” GasGun reach 10 – 20 feet horizontally into the formation with very little vertical fracture growth. The multiple fracture network created nearbore makes it a great tool for cleaning up nearbore damage and beyond.

Result: “JD, the well is doing quite well. We are kicking around using the GasGun in conjunction with our perforating in another well we are working on. Currently the well we treated with GasGun is making 5.289 mmcf 8 bcpd 7 bwpd 1,600 psi ftp on a 20/64 choke. We are very pleased with the results.”-Operator

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<th>Pos</th>
<th>Clearance (in)</th>
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<th>Outer String</th>
<th>Not Used</th>
<th>Formation Penetration</th>
<th>Total Target Penetration</th>
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