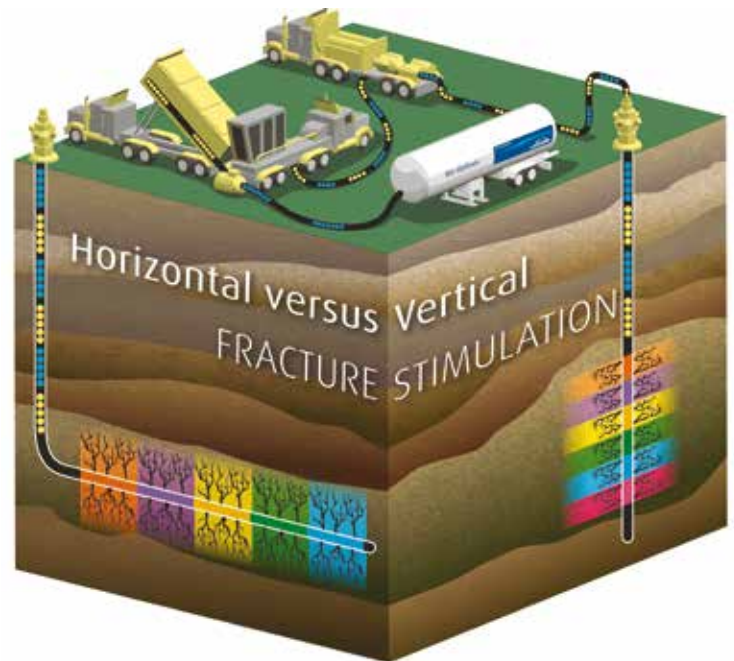


Benefits of Energized Solutions in Fracturing



A Supplier's Perspective: Fracturing Applications for CO₂ and N₂



Unconventional reservoirs present unique challenges for energy producers and oilfield service companies that seek to extract the maximum economic lifetime potential from their wells. These reservoirs, like shale, tight sands and coalbed methane (CBM) formations, are defined by their low permeability, low-to-no porosity and need for stimulation for economic production. No two formations are alike and often are characterized by significant variability within the same formation, thus requiring varying stimulation techniques. Unleashing the value of these unconventional reservoirs relies heavily on the methods of horizontal drilling combined with hydraulic fracturing.

Unconventional reservoirs and their fracturing are essential to reducing U.S. dependence on foreign sources of oil and natural gas. The U.S. Department of Energy projects that shale gas will comprise over 20% of the total U.S. gas supply by 2020. Drilling horizontally through a layer of shale, and then fracturing along the length of that layer (Figure 1), increases the surface area contact within the producible reservoir and encourages previously trapped hydrocarbons to flow to the wellbore. Increasing the Expected Ultimate Recovery (EUR) of the well depends on using the best fracturing technique for the type of unconventional play at hand.

More common fracturing fluids used today are gelled or water-based. Carbon dioxide (CO₂) and nitrogen (N₂) share a long history as fluids used for the successful hydraulic fracturing and stimulation of wells. Recent studies¹ indicate that fracturing with solutions energized by CO₂ or N₂ can economically achieve significantly more hydrocarbon recovery than non-energized approaches. One such study² found that use of energized fluids improved well performance by 1.6 to 2.1 times compared to non-energized solutions. This paper, written from the perspective as an industrial gas provider, not that of an energy producer or service provider, reviews when and why to consider using energized fluids.

Figure 1. Unleashing value: Horizontal drilling combined with hydraulic fracturing increases the surface area contact within the producible reservoir and encourages previously trapped hydrocarbons to flow to the wellbore.

Fracturing Challenges

The ultimate goal of well stimulation is to achieve the maximum EUR, defined as maximum productivity over time at the lowest unit cost. Achieving economically desirable fracture penetration and conductivity is particularly challenging in unconventional reservoirs. Fracturing with fluids that are not energized can leave liquids trapped in low-permeability, tight, depleted or water-sensitive formations. Fluid remaining in the formation lowers the conductivity of the reservoir³, reducing or impeding the flow of oil and gas. Often times, in water-based fracturing fluids, the majority of the water is never recovered. Energizing the fracturing fluid with CO₂ or N₂ will improve the total flowback volume and rate, as well as, when foamed, significantly lower the total and liquid leak-off coefficient⁴, minimizing fluid retention.

Proppant, a sand or ceramic material used to keep the fractures propped open, can be improperly deposited, resulting in blocking or impeding flow. Foamed energized fracturing fluids provide superior proppant transport properties. Gelled fracturing fluids must be flushed from the formation to clean out as much residue as possible from the proppant pack. Adding CO₂ or N₂ to the fracturing fluid reduces the need for gel volume and therefore the amount of gel left behind in the proppant pack. And, as issues continue to arise around water-based fracturing using a tremendous amount of water, adding CO₂ or N₂ can reduce or eliminate the water volume. According to Chesapeake Energy Corp., the second largest producer of natural gas and a Top 15 producer of oil and natural gas liquids, fracturing one of its typical horizontal deep

A Look at Unconventional Reservoirs



Shale: As a fine-grained, sedimentary rock, shale is heterogeneous. No two are alike; they vary aerially, vertically, and along the wellbore, with in-situ stresses and geologic variances. Shale is easily breakable into parallel layers. With permeability in the Nano Darcy range, it is soft yet does not disintegrate when wet; instead it becomes fine grain silt and mud. To extract embedded oil and gas, shale must be fractured.



Tight sands: These hard rock, limestone, sand, or sandstone formations have low vertical permeability, in the Micro Darcy range. They are laminated structures. There is no significant gas flow without fractures – naturally occurring or induced.



Coalbed methane: Coal deposits are located in or around coal seams, often near earth's surface. Natural fractures are often filled with water and absorbed gas, making water removal a key extraction challenge.

shale natural gas or oil wells requires, on average, 4.5 million gallons of water. Acquiring, transporting, storing, recovering and recycling, or disposing of that water presents an ever increasing challenge.

Fracturing Treatment Choices

When faced with water restrictions or prohibitive management issues, depleted zones, water-sensitive reservoirs, low pressure or strong capillary forces, it is important to have alternatives that can better suit site-specific fracturing needs. Energy producers and their service providers have many choices for fracturing treatments. They can choose from gels and polymers, slick or acid water, gases like CO₂ or N₂, used in a variety of solutions or on their own, or various combinations of all these. Gels and polymers are typically used when higher viscosity is required and tend to promote wider, shorter fractures in more ductile rock. Slick or acid water, lower viscosity solutions, promote longer, thinner fractures in more brittle rock. Energized gases, specifically CO₂ or N₂, can be mixed, foamed, gelled or emulsified to cover the range of viscosities and various applications. High-quality foams (>/=65% gas by volume) were developed as viable fracturing stimulation fluids for oil and gas wells back in the 1970s⁵. Historical estimates indicate that up to one-third of fracturing operations in North America have used energized solutions.

To select the appropriate fluid, producers consider a number of operational factors and reservoir characteristics in fracturing design. Critical reservoir data includes insight into the permeability, pressure, water sensitivity, rock mechanics or formation stresses and natural fractures, leak-off, and sometimes temperature of the formation, as well as any restrictions or requirements of production for gas pipelines. Operational considerations include the cost of acquiring fracturing fluid, managing that fluid (transportation, storage, recovery and recycling/disposal), fluid sustainability and availability, the environmental impact and overall productivity, including time-to-complete and time-to-production – getting saleable hydrocarbons flowing to the pipeline.

What Does Success Look Like?

Before fracturing, producers use simulation software to design the fracture. Existing commercially available simulators do not, however, account for the phase behavior and compositional changes during an energized fracturing treatment (see Figure 2). This makes modeling the effective productivity of an energized fracturing treatment less reliable. Researchers at the University of Texas at Austin have designed a simulator that does factor in compositional and phase behavior changes for more accurate modeling of a stimulation utilizing energized fluids for hydraulic fracturing. To measure the actual effectiveness of the hydraulic fracturing stimulation, microseismic, logging tools, tilt meters, Mine-back experiments and pressure behaviors are among the monitoring techniques used to determine fracture propagation.

To strive for the greatest Expected Ultimate Recovery (EUR) of the well in the most economically effective way, both performance and economy must be considered – the maximum productivity over time at the lowest overall cost. Typically, EUR is projected over 10 years based on actual production rates taken at 30, 60 and 90 days. The decline curve – representing the drop in production over time – is projected from these actuals, with low, best and high estimates to cover the range of uncertainty. Costs factored into EUR stimulation economics should include materials acquisition, materials management (including recovery, recycling and removal/disposal), horsepower, labor and refracturing (subsequent efforts to fracture again).

Too often, much of the focus is on the well's initial performance. Encouraged by time-to-production using familiar techniques, producers may neglect to consider alternatives that could minimize the slope of the decline curve. Adding CO₂ or N₂ to the fracturing treatment has been shown to optimize overall productivity, increasing EUR, even though the initial acquisition cost of these gases can be higher than non-energized slick or acid water. The increased productivity on the wells effectively reduced unit production costs.

Composition and Phase Behavior

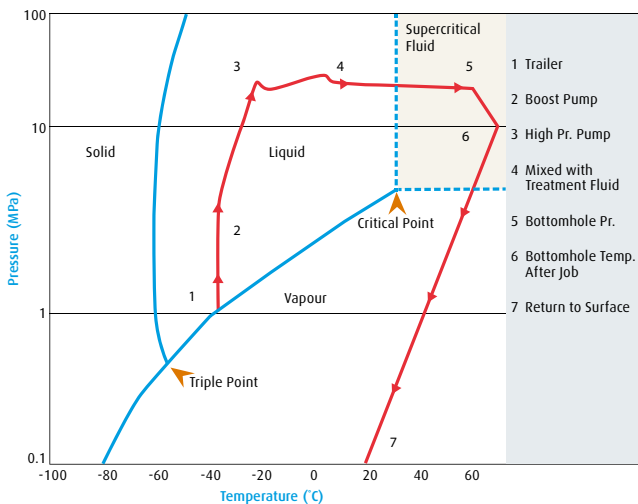


Figure 2. Phase behavior changes of CO₂ during the hydraulic fracturing process.

The Advantages of Energized Solutions

The flexibility of energized solutions allows for the hydraulic fracturing fluid to be mixed according to the technological needs of unconventional reservoirs. They provide more rapid and complete treatment fluid recovery, help to clean without swabbing and reduce formation damage by minimizing the amount of aqueous fluids introduced to the formation. In addition, energized solutions offer the ability to have superior proppant-transport properties and, in the case of underpressured or depleted zones, provide enhanced energy for hydrocarbon recovery. Flexibility in solution viscosity allows for a more uniform deposition of proppants, thus improving conductivity of the propped area to improve the flow of hydrocarbons. In unconventional reservoirs, energized solutions provide the necessary lift to move hydrocarbons in low-pressure zones or areas with strong capillary forces. The solubility and miscibility properties of CO₂ provide greater opportunity to energize the flow of more viscous hydrocarbons.

Avoiding damage, defined as any induced reservoir change that inhibits or restricts hydrocarbon flow, during well stimulation is critical. Proppant can cause damage. Too little, too much, improperly placed or of poor quality, and it can block the flow of oil and gas. Fractures too far apart, too close together or that tap into non-productive areas of the reservoir can create damage. Residue left from polymers and gels used in fracturing can impede flow through the proppant pack, while overflushing to remove the residue can create fines – superfine particles whose migration blocks flow. Leak-off, both a reservoir and treatment fluid property, in aqueous or liquid form can also block flow. Because of liquid leak-off, the water saturation increases, thereby decreasing the relative permeability to gas, and may play a significant role in the damage to gas reservoirs. Energized solutions, however, use less water than conventional fracturing treatments and provide energy for recovery of induced fluids while decreasing the fluid leak-off potential, thus minimizing reservoir damage. Less water means less potential for clay swelling, fines migration and fluid retention. Less damage

Effect of Drawdown Pressure

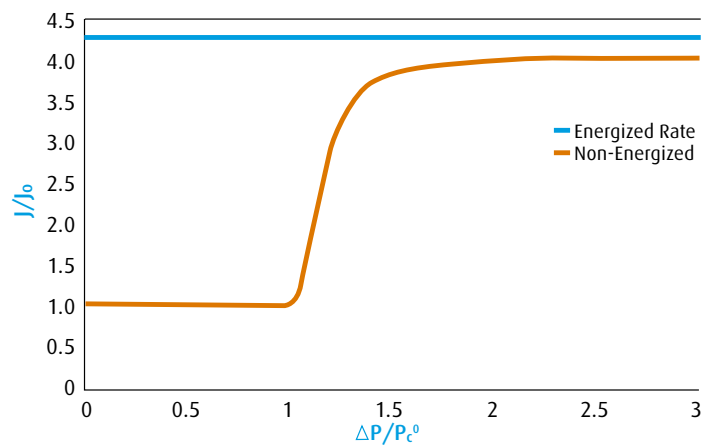


Figure 3. Comparison of the predictive productivity (unitless measure of J/J_0) of energized solutions vs. non-energized water fracture stimulations.

enhances flow for effective flowback, thus reducing the time it takes to move into production while increasing overall production.

Energized solutions are ideal for reservoirs with low permeability, water sensitivity, underpressured or depleted zones, or poor flowback caused by low pressure or strong capillary forces. They are also used for refracturing wells where production has declined over time. Because they can be foamed or emulsified to cover a range of viscosities to provide superior proppant-transport properties with slow settling rates, they are good for shale requiring fracture length or reservoirs rich in liquids that benefit from fracture width⁶. When foamed, energized solutions significantly reduce fluid leak-off into the formation as well as reduce gel volume requirements, improving fracture conductivity.

Proven Effective

Friehauf and Sharma⁷ compare the predictive productivity of energized versus water fracture stimulations (as shown in Figure 3). Their paper provides the theoretical framework supporting the improved productivity results utilizing energized solutions for fracturing. Recent field studies evaluating energized solutions further validate this by showing that economic EUR can be optimized using this alternative treatment. From South Texas to Canada's Montney basin to the Marcellus shale (see Figure 4), energized solutions have been proven effective. A 2011 study of the Montney basin showed that the use of energized fluids improved well performance by 1.6 to 2.1 times compared to non-energized solutions (see Figure 5). Energized solutions were proven to significantly increase well productivity more cost effectively, presenting opportunities to reduce fracturing resources such as water consumption and proppant required, and to reduce injection rates and injection pressures. They are ideally suited for use in tight, depleted or water-sensitive formations, or to enhance the mobility of more viscous hydrocarbons around and through the wellbore.

Cumulative Gas Production

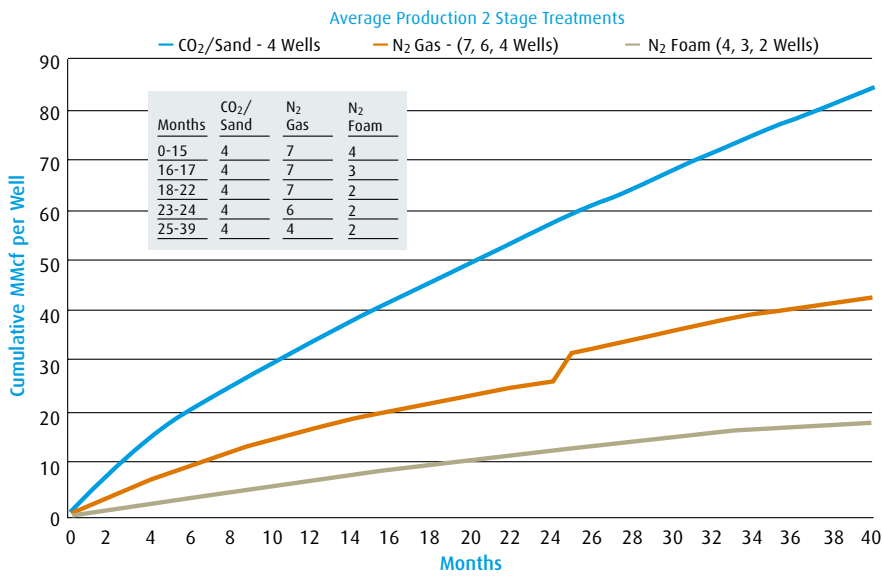


Figure 4. Cumulative gas production comparison utilizing energized fluids for fracturing. Devonian Shale, Pike County, Kentucky.

Improved Productivity Performance

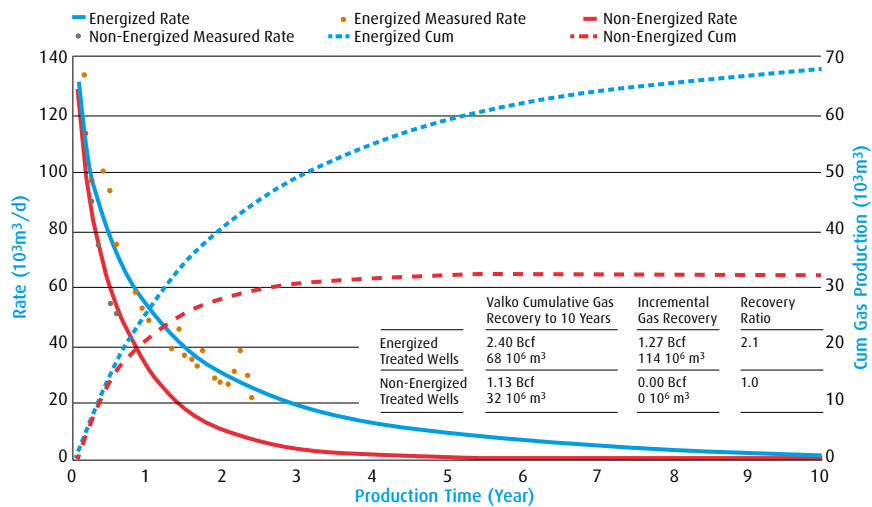


Figure 5. Averaged well 10-year Valko Decline Analysis from "Improved Productivity Performance of Energized Fracturing Fluid over Non-Energized: A Montney Study."

Benefits of Using CO₂

Beyond the general benefits of an energized fluid for hydraulic fracturing, CO₂ has enhanced properties to make it the ideal gas to provide energy to aqueous solutions and liquid hydrocarbons. It offers high solubility in water that increases its ability for long sustained solution-gas drive, as well as excellent recovery of hydraulic fluids. With a density similar to water, liquid CO₂ can be pumped into the well at pumping pressures similar to water. At reservoir conditions, CO₂ is almost always supercritical with a specific gravity of 1 or sometimes higher. As the CO₂ penetrates the fractured zone, it displaces fluid in the reservoir rock and leaves from the reservoir as a gas. In addition, CO₂ has excellent miscibility in hydrocarbons and compatibility with formations fluids, allowing for enhanced mobility and recovery. Where readily available, CO₂ offers additional benefits to energized solutions.

Benefits of Using N₂

N₂, like CO₂, can be used alone or mixed with other components, and is typically more readily available in unconventional reservoir plays. It can be injected into the well in pure form as a gas or as a foam. It works effectively without proppant in formations where the rock effectively props itself. For liquid-free stimulations, it can be ideal for fracturing dry, shallow formations, such as CBM. Though less soluble than CO₂, N₂ can ensure presence in the invaded zone with additional measures, such as delaying flowback to allow the gas phase to penetrate. Because it is an energized treatment, N₂ improves reservoir flow, providing trapped hydrocarbons with a lift, and reduces leak-off while improving fracturing fluid recovery. When foamed, it reduces the amount of water used, also contributing to reduced total and liquid or fluid leak-off. Because it has a lower density than water, N₂ requires more horsepower to achieve desired pumping pressure and is more practical in lower total depth wells than CO₂.

Supply of CO₂ and N₂

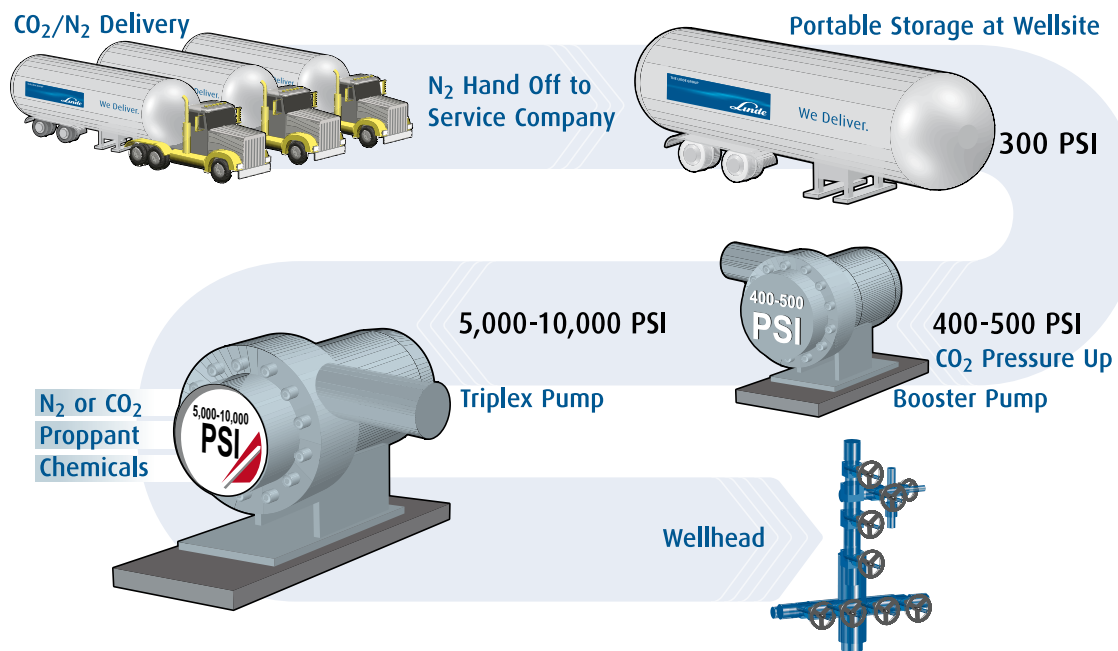


Figure 6. Supply of CO₂ and N₂.

Footnotes

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- **2:** Burke, L.H. and Nevison, G. W. 2011. **Improved Hydraulic Fracture Performance with Energized Fluids: A Montney Example.** Recovery-2011 CSPG CSEG CWLS Convention.
- **3:** Akrad, O., Miskimins, J., and Prasad, M. 2011. **The Effects of Fracturing Fluids on Shale Rock Mechanical Properties and Proppant Embedment.** Paper SPE 146658 presented at the SPE Annual Technical Conference and Exhibition, Denver, CO, 30 October -2 November.
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- **5, 6:** **Hydraulic Proppant Fracturing and Gravel Packing,** Detlef Mader, Elsevier 1989.
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