Enhanced Unconventional Oil and Gas Production with Nitrogen Fracturing

Oilfield Services

An Air Products trailer making a liquid nitrogen delivery to an Air Products mobile storage vessel staged at the well site.
The Expansion of Unconventional Oil and Gas

Oil, the world’s most important energy source, has long been the catalyst for worldwide expansion of transportation and economic development. Likewise, natural gas is a vital energy source that consists of a mixture of hydrocarbon gases, such as methane, ethane, butane, as well as carbon dioxide, nitrogen, and hydrogen sulfide, located in deep rock formations beneath the earth’s surface. The supply of oil and gas has a significant impact on our everyday lives. We depend on these fuels for transportation, electric power generation, manufacturing and commercial operations, domestic usage, and other applications.

With the worldwide population expected to exceed 9 billion by 2050 and the fast economic development in Asian and South American countries, there is unprecedented pressure to meet the growing global demand for energy by the expansion of unconventional oil and gas sources.

The International Energy Agency (IEA) predicts that the global demand for natural gas will increase by 50% from 2010 to 2035, making the exploration of unconventional gas increasingly important as conventional gas reserves become more depleted (see Figure 1).

In the US alone, the annual unconventional tight oil production is projected to increase from 2 million barrels of oil per day (mbd) in 2012 to 4.4 mbd in 2020 [1].

The economic development of unconventional oil and gas sources has been driven by significant technological advancements in horizontal drilling and hydraulic fracturing. Hydraulic fracturing is a well stimulation process used to enhance the productivity of oil and gas wells by applying a hydraulic force using a fluid to create small fractures in deep rock formations.

Despite the unprecedented growth in the practice of hydraulic fracturing, operators are continuously faced with the financial and technical challenge of completing wells at compelling economics. The design and selection of well stimulation fluids, known as fracturing fluids, play a major role in improving well completion economics because an effective fracturing fluid can significantly enhance hydrocarbon production rates. Another challenge faced by operators is that the harvesting of most of the known unconventional oil and gas resources is not yet commercially viable; hence, significant technological advancements in well stimulations methods will be required to facilitate the production of increasingly challenging reservoirs.

Figure 1. U.S. natural gas production, 1990-2035 (trillion cubic feet)

Figure 2. Hydraulic Fracturing Process
(Source: US IEA)
Nitrogen Fracturing

Operational Advantages of Nitrogen Fracturing

- **Rapid cleanup** of flowback fluid
- **Non-damaging** in water sensitive formations
- Enhanced production of natural gas and oil in **low permeability** and **low porosity** formations
- **Beneficial for shallow formations**
- **Highly beneficial in** depleted gas reservoirs due to energizing properties
- **Alternative fracturing fluid to slickwater,** which is beneficial in geographical regions prone to water shortages and drought, or in areas with strict water regulations
- **Significantly reduces water requirements** and the use of chemical additives

Water-based fracturing fluids (most commonly known as “slickwater”) are widely used for hydraulic fracturing because they are inexpensive and offer good proppant transport into the fracture. However, slickwater is unsuitable for water-sensitive formations because it can cause water saturation around the fracture and clay swelling, which may significantly hinder the mass transport of hydrocarbons from the fracture to the well bore. The use of energized or foam fracturing fluids offers an excellent alternative to slickwater in **water-sensitive formations, depleted reservoirs,** and **shallow formations.**

The main types of nitrogen fracturing fluids are **energized, foam, straight gas (mists),** and **cryogenic liquids.** Foam fracturing fluids typically consist of a water-based system and a gas phase of nitrogen in the range of 53% to 95% by volume. Below 53%, the fracturing fluid is considered energized, and above 95%, the fracturing fluid is considered a mist. Cryogenic liquid nitrogen has also been used as a fracturing fluid; however, it is rarely employed in commercial operations due to special piping and equipment requirements.

**Nitrogen Gas Fracturing**

Nitrogen gas fracturing is used primarily for water-sensitive, brittle, and shallow unconventional oil and gas formations. The use of nitrogen prevents clay swelling that would otherwise be caused by slickwater. Pure gaseous nitrogen produces best results in brittle formations that have natural fractures and stay self-propped once pressure pumping is completed. This is because nitrogen is an inert and compressible gas with low viscosity, which makes it a poor proppant carrier. In addition, due to the low density of gaseous nitrogen, the main applications for nitrogen gas fracturing are shallow unconventional plays, namely coal bed methane, tight sands, and shale formations up to 5,000 ft in depth. Formations best suited for nitrogen gas fracturing also tend to have low permeability (less than 0.1 md), low porosity (less than 4%), and a reservoir pressure gradient of less than 0.2 psi/ft.

**Nitrogen Foam Fracturing**

Nitrogen foams contain between 53% and 95% volume of nitrogen with the balance composed of water and additives, which gives them similar applicability as pure gaseous nitrogen. The ability to combine water and nitrogen in different volume fractions means that fluid viscosity can be adjusted for best performance. With all the concerns in local communities surrounding water usage for fracturing, nitrogen foam fracturing provides the benefit of reduced water consumption. For the same reason, the amount of additives in the aqueous solution is reduced by the equivalent volume proportion of nitrogen used. This means reduced chemical loading of the fracturing fluid, which is environmentally and financially beneficial.

**Nitrogen Energized Fracturing**

Energized fluids contain less than 53% volume of nitrogen with the balance composed of water and additives. This means that the gas is used to energize the liquid phase to facilitate water unloading in low-pressure formations. Because of higher liquid volume concentrations, energized fracturing tends to be amenable to deeper formations (up to 8,000 ft in depth) than its foam or pure gaseous nitrogen counterparts. It is also typically used when the reservoir pressure gradient ranges from 0.2 to 0.5 psi/ft.
Better Life-Cycle Economics with Nitrogen Fracturing

From a service cost perspective alone, nitrogen fracturing is often thought to be higher cost than baseline slickwater. However, with increased regulation affecting water usage and disposal in fracturing processes, operators will likely face growing pressure to treat, recycle, and re-use flowback water. The technological and financial challenges of dealing with the hazardous contaminants in flowback water make nitrogen fracturing very competitive. The same is true for arid locations faced with escalating cost of fresh water.

In certain shale plays, nitrogen fracturing has offered superior performance measured as estimated ultimate recovery (EUR) of natural gas compared to slickwater, which means that the cost of nitrogen fracturing is lowered on a normalized production basis [2, 3].

Case Study A: Devonian Big Sandy Play

Located in the Appalachian Basin, the Devonian shale gas play includes several formations such as the Lower Huron, Cleveland, and Rhinestreet, which are located in Kentucky, Virginia, and West Virginia. Evaluating the characteristics of the Devonian shale rock reveals that it has low permeability, low porosity, high water sensitivity, and a high proportion of natural fractures. Due to these characteristics, nitrogen fracturing has been the most commonly used well stimulation method since 1978 [4, 5].

To optimize the well completion process in the Lower Huron Shale region, Wozniak et al. carried out a comparative study into different nitrogen fracturing fluids as shown in Table 1 [3].

Moreover, Wozniak et al. concluded that the nitrogen gas treatment was approximately US $50,000 less expensive than nitrogen foam treatments[3].

Figure 3. Map of the Devonian Big Sandy Play (Source: US EIA)

<table>
<thead>
<tr>
<th>Fluid Type</th>
<th>Nitrogen Volume (scf)</th>
<th>Water Volume (bbl)</th>
<th>Sand (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>1,000,000</td>
<td>&lt;10</td>
<td>0</td>
</tr>
<tr>
<td>Foam A</td>
<td>800,000</td>
<td>300</td>
<td>40,000</td>
</tr>
<tr>
<td>Foam B</td>
<td>900,000</td>
<td>50</td>
<td>15,000</td>
</tr>
</tbody>
</table>

Their results indicated that the EUR obtained with nitrogen gas fracturing was 28% higher than with nitrogen foam and 8% higher than with hybrid nitrogen.
**Case Study B: Montney Play**

The Montney shale gas play is located in the Western Canada Sedimentary Basin spanning a total area of 2,961 km$^2$, where it is of great importance to the Canadian natural gas supply. Much of the Montney play is characterized by unconventional formations that can be adversely affected by slickwater fracturing, thereby lowering the production rate of the well. Therefore, many operators within the Montney formation use carbon dioxide and nitrogen fracturing solutions.

**Enhanced Cumulative Production of Natural Gas**

In this paper, energized fracturing with nitrogen is reported to cost 15% more than slickwater when total fracturing cost is considered. That additional cost is offset by an average increase in natural gas EUR using energized fracturing of 11% (see Figure 4).

Under marginal pricing assumptions for natural gas, the paper reports an incremental value of approximately US $1.4 MM. It is worth noting that the analysis performed in [2] assumes typical water disposal costs. However, if water recycling costs were considered, the comparative economics of nitrogen foam would be enhanced. This is because the water volume is 11% lower than slickwater alone, and recycling costs are at least 4 times more expensive than the deep well injection disposal method assumed in the paper.

**Table 2: Comparison of Fracture Treatments in the Montney Play**

[2] SPE 149344

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stage Count</th>
<th>Liquid Volume per Stage (m$^3$)</th>
<th>Proppant Mass per Stage (tons)</th>
<th>Total Fracturing Treatment Cost ($MM)</th>
<th>Total Fracture Cost Increase (%)</th>
<th>Energized EUR Improvement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slickwater</td>
<td>5</td>
<td>955</td>
<td>177</td>
<td>$1.34</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nitrogen Foam</td>
<td>5</td>
<td>853</td>
<td>196</td>
<td>$1.57</td>
<td>15%</td>
<td>11%</td>
</tr>
</tbody>
</table>

**Figure 4. Averaged Decline Analysis for Energized and Non-Energized Solutions** [2] SPE 149344
Case Study C: Coal Bed Methane Plays

Nitrogen fracturing fluids are widely used for hydraulic fracturing and enhanced coal bed methane recovery across coal bed methane plays in North America.

The Greater Green River Basin is one of the large coal bed methane plays in the US located in central Wyoming and spanning an area of approximately 19,000 square miles. Fredd et al. carried out field-testing, laboratory testing and simulations to compare the performance of nitrogen foam to slickwater for this basin. The authors report that the field data demonstrated that nitrogen foam outperformed slickwater by providing 20-30% improvement in estimated ultimate recovery (EUR) of natural gas [6].

Furthermore, Fredd et al. report that the results from field-testing in other shale plays showed that nitrogen foam offered a great deal of success. For example, in the Devonian Shale play, the data showed that nitrogen foam offered a 59% one year cumulative production increase in comparison to slickwater.

Other cited advantages of the use of nitrogen foam included reduced formation damage, improved cleanup, and compliance with US environmental regulations related to drinkable groundwater.

Figure 5. Generalized geologic map of the Greater Green River Basin showing the Tertiary rocks and undifferentiated Cretaceous rocks (Source: USGS)
Case Study D: Simulation and Design of Energized Hydraulic Fractures

In North America, energized fracturing is extensively used for stimulating depleted tight gas formations. Friehauf & Sharma developed a simulation model for energized hydraulic fractures to determine when energized fracturing is beneficial for tight gas recovery [7].

The main conclusions from the simulation model are:

- At low drawdown pressures, energized fluids outperform non-energized fluids because they stimulate the formation by means other than fluid recovery.

- When the drawdown pressure is less than 1.5 times the minimum drawdown pressure, energized fracturing is recommended.

- At high drawdown pressures, the difference between energized fluids and non-energized fluids is negligible because all damage is removed regardless of the composition in the invaded zone. Therefore, the use of energized fluids is not justified.

- Energized fluids should be used in low permeability rocks when drawdown pressures are low.

Figure 6. Effect of Drawdown Pressure. Energized fracturing is recommended when the target drawdown pressure is not achieved [7] SPE 149344

Conclusions

Nitrogen fracturing has provided enhanced oil and gas recovery in various unconventional plays across North America. Many operators reported that nitrogen fracturing is particularly suitable for shallow formations and depleted reservoirs and provides significant performance benefits compared to slickwater fracturing, namely, improved EUR rates, rapid cleanup of flowback water and reduced formation damage (particularly for water sensitive formations). These performance benefits enable operators to achieve improved life cycle economics with nitrogen fracturing, especially with increasing cost of fresh water in arid locations and the potential for increasing cost of flowback water treatment under tighter water regulations. Nitrogen fracturing fluids also have the additional environmental benefits of reduced water and chemicals consumption.
How may we help you?

Air Products’ complex network of multiple delivery solutions enables us to meet variable, high-volume demand. Nitrogen can be supplied directly from multiple production plants (which could be located hundreds of miles from the well), from permanent staging areas, and from mobile staging areas nearer the well that can be moved as jobs move.

Permanent staging area
N₂ stored in permanent tanks at various locations.

Staging and delivery at well site
Delivery to customer transport.

Mobile staging area near well site
N₂ stored in mobile queens.

Staging/storage in mobile queens.

Please consult the Air Products Oilfield Services Brochure for details regarding our nitrogen production facilities and the various services that we provide to oilfield customers.

References

1. IHS, America’s New Energy Future: The Unconventional Oil and Gas Revolution and the US Economy, 2012, IHS.
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For more information, please contact us at:

**Air Products**
7201 Hamilton Boulevard
Allentown, PA 18195-1501
Tel 800-654-4567
Tel 610-706-4730
Fax 800-272-4449
Fax 610-706-6890
Email gigmrktg@airproducts.com