Hydraulic Fracturing Overview

The development and production of unconventional shale gas reservoirs, including the Marcellus Formation underlying a large part of Pennsylvania, represents a growing source of our natural gas reserves. Although these formations contain substantial quantities of natural gas, their limited natural vertical and horizontal permeability may significantly restrict the ability of the gas to readily flow into a wellbore. In an effort to increase the gas flow of these shale gas plays, well stimulation operations known as hydraulic fracturing, or "fracing" of the formation, is an increasingly common procedure undertaken to enhance the permeability characteristics of the formation and subsequently promote the economic recovery of the natural gas.

Hydraulic fracturing techniques have been refined through years of development in other shale gas plays, notably the in Barnett Shale in Texas. Most enhancements have focused on the nature of the frac additives and the propping agents such as fine sand or ceramic material employed in the fracing process. Today, well stimulation in the Marcellus Formation in Pennsylvania is a highly specialized operation that utilizes computer simulation/modeling to design the fracing process, develop specifications on the volumes of fluid and proppant to use, calculate the pressure required, and determine the composition of the fracing fluid. This data is integrated with lithologic and other characteristics unique to the formation, such as depth, temperature and thermal maturity, and the structural characteristics of the shale. Collectively, these aspects are used to determine the "fracability" of the formation.

Horizontal well drilling and completion is another technology used in the Marcellus Formation to increase the productivity of a gas well by maximizing the length of the wellbore through the target formation. Current drilling practices in the Marcellus shale in Pennsylvania utilize both horizontal and the more traditional "vertical" wells. While a vertical well may be exposed to as little as 50 feet of the formation, horizontal wells may be developed with a lateral borehole extending a length of 2,000 feet to more than 6,000 feet into the target formation. Vertical wells require less capital investment compared to a horizontal well, but are less productive than a horizontal well. Regardless of the completion technique, however, both vertical wells and horizontal wells completed in the tight gas formations such as the Marcellus usually require some type of formation stimulation such as hydraulic fracturing.

When drilling a well into the Marcellus shale or another oil and gas-bearing formation, an initial string of drive pipe, or conductor pipe, is installed to prevent unconsolidated materials such as soil, sand and gravel from caving in during well drilling. Next, a "surface string", or casing smaller in diameter than the conductor pipe, is installed after drilling below the entire vertical length of fresh groundwater. This casing string must be properly cemented to the surface to protect all potable groundwater sources from production-related activity in the wellbore that is drilled and completed to the target

formation. If coal is present, another string of casing will be installed to isolate this interval. An intermediate casing string may also be installed under certain conditions to isolate, stabilize or provide well control to a greater depth than that provided by the surface casing or coal protection casing. Each casing string will be deeper, but successively smaller in diameter. As mentioned above, the annular space between the borehole and each casing string is typically cemented to the surface or to a prescribed height above the bottom of the casing string, to ensure isolation and protection of each zone. Finally, a production interval is drilled, which may be several tens of feet to several hundred feet in a vertical Marcellus well, or up to several thousand feet in a horizontal well. This zone typically is electronically analyzed or "logged" by a company that specializes in this service, and is achieved by lowering an electronic device on a wireline into the wellbore, where data on porosity, density and other characteristics are analyzed to determine the production potential of the formation. After the well has been logged, the production casing is installed in the borehole and cemented to isolate these zones.

In Pennsylvania, hydraulic fracturing operations in the Marcellus Formation occur only after the multiple strings of casing as described above have been installed in the wellbore. Chapter 78 of the DEP regulations require the installation of the protective surface casing through the entire vertical length of fresh groundwater and, if present, coal isolation casing in the wellbore as well. In addition, since the Marcellus Formation typically is encountered at depth ranging from 5000 to 9000 feet, this offers thousands of feet of vertical separation between underground sources of drinking water and the deeper production/target zone, inhibiting communication between fractures in the target zone, induced during hydrofracturing operations, and any overlying fresh water aquifers.

Hydraulic fracturing may be performed on as few as a single interval in a vertical well. Horizontal wells, however, by virtue of their significant wellbore length in the target formation, are generally isolated into several discrete intervals along the horizontal wellbore (approximately 4-20 intervals for each horizontal well), with each interval requiring its own fracing stage. This is due to the difficulty in maintaining pressures sufficient to induce fractures over the complete length of the lateral leg.

Before an operator or a service company performs a fracing operation on a vertical or horizontal well, tests are conducted to ensure that the well and all necessary equipment is in safe working order and will endure the operational pressures of the fracturing operation. This is followed by a procedure that perforates the production casing in the wellbore. The locations of where to perforate the production casing are determined during the well logging procedure. Perforations are created by means of a specialized tool lowered into the well on a wireline. When completed, perforations in the casing will allow fluids to enter the fractures created during the subsequent fracing operation and also allow gas to flow into the wellbore when the well enters its production phase.

Each interval isolated in a fracing operation, whether a vertical well or a horizontal well, is subject to a specific sequence of fluid additives, each with its own engineered purpose to facilitate the production of gas from the well. Hydraulic fracturing of Marcellus wells in Pennsylvania typically utilizes a water-based fluid known as "slickwater" frac.

Slickwater fracs are predominantly water, pumped at high pressure, with lesser amounts of sand, along with very dilute concentrations of certain additives and chemicals designed to stimulate the formation, enhance the return, or "flowback" of the slickwater solution following well stimulation, and increase the production of gas from the reservoir. The particular chemistry of the frac fluid may vary from site to site. Each frac interval in a horizontal well may require up to 500,000 to 1 million gallons of water. Vertical wells use the same solutions but typically require two to three times the volume of a single horizontal frac interval. Note, however, that collectively, the total volume of frac fluid needed for a horizontal well will be significantly higher than that needed for a vertical well. The term "slickwater" refers to friction-reducing agents, such as potassium chloride, polyacrylamide or other chemicals, added to the water to reduce the pressure needed to pump the fluid in the wellbore. These additives may reduce tubular friction in the wellbore by 50 to 60%.

The sequence of additives in fracing a particular interval typically consists of:

1. An *acid stage*, consisting of several thousand gallons of water mixed with a dilute acid, such as hydrochloric or muriatic acid. This serves to clear cement debris in the wellbore and provide an open conduit for other frac fluids, by dissolving carbonate minerals and opening fractures near the wellbore.

2. A *pad stage*, consisting of approximately 100,000 gallons of slickwater without proppant material. The slickwater pad stage fills the wellbore with the slickwater solution (described below), opens the formation and helps to facilitate the flow and placement of proppant material.

3. A *prop sequence stage*, which may consist of several substages of water combined with proppant material, which consists of a fine mesh sand or ceramic material, intended to keep open, or "prop" the fractures created and/or enhanced during the fracing operation after the pressure is reduced. This stage may collectively use several hundred thousand gallons of water. Proppant material may vary from a finer particle size to a coarser particle size throughout this sequence.

4. A *flushing stage*, consisting of a volume of fresh water sufficient to flush the excess proppant from the wellbore.

Other additives commonly used in the fracing solution employed in Marcellus wells include:

- A *dilute acid solution*, as described in the first stage, used during the initial frac sequence. This cleans out cement and debris around the perforations to facilitate the subsequent slickwater solutions employed in fracturing the formation;
- A *biocide or disinfectant*, used to prevent the growth of bacteria in the well that may interfere with the fracing operation. Biocides typically consist of bromine-based solutions or glutaraldehyde.

- A *scale inhibitor*, such as ethylene glycol, used to control the precipitation of certain carbonate and sulfate minerals;
- *Iron control/stabilizing agents* such as citric acid or hydrochloric acid, used to inhibit precipitation of iron compounds by keeping them in a soluble form;
- *Friction reducing agents*, also described above, such as potassium chloride or polyacrylamide-based compounds, used to reduce tubular friction and subsequently reduce the pressure needed to pump fluid into the wellbore. The additives may reduce tubular friction by 50 to 60%. These friction-reducing compounds represent the "slickwater" component of the fracing solution.
- *Corrosion inhibitors*, such as N,n-dimethyl formamide, and *oxygen scavengers*, such as ammonium bisulfite, are used to prevent degradation of the steel well casing.
- *Gelling agents*, such as guar gum (a common food additive), may be used in small amounts to thicken the water-based solution to help transport the proppant material.
- Occasionally, a *cross-linking agent* will be used to enhance the characteristics and ability of the gelling agent to transport the proppant material. These compounds may contain boric acid or ethylene glycol. When cross-linking additives are added, a breaker solution is commonly added later in the frac stage, to cause the enhanced gelling agent to break down into a simpler fluid so it can be readily removed from the wellbore without carrying back the sand/proppant material.

The additives mentioned above are relatively-common components of a water-based frac solution used in tight gas formations such as the Marcellus Shale in Pennsylvania. However, it is important to note that not all of the additives listed here are used in every hydrofracturing operation; the exact "blend" and proportions of additives will vary based on the site-specific depth, thickness and other characteristics of the target formation.

Nitrogen-based frac solutions are also occasionally used to stimulate shale gas plays. These "foam fracs" typically require only 25 % of the water demand needed for a slickwater frac. However, these nitrogen-based foam fracs are effective only in formations that reside at relatively shallow depths. In Pennsylvania, where the Marcellus Formations normally occurs at greater depths, the increased formation pressure limits the ability of foam-based fracs to effectively fracture the formation and deliver the proppant. For this reason, water-based frac solutions are more common in Pennsylvania.

As exploration, development and production continues in the Marcellus Formation, the expectation is that both the fracing process in general and the additives employed in this process will be refined and enhanced to increase the availability of gas from the formation. This process, however, must be performed in an environmentally-protective manner. Accordingly, the Department of Environmental Protection will continue to be proactive in its mission in overseeing the hydraulic fracturing process, as well as all aspects of oil and gas well drilling, stimulation, production and site restoration.