Considerations for development of Marcellus Shale gas

Operators are working to optimize fracture patterns for improved production and to ensure containment and efficient use of frac fluids.

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Shale gas resources extend across the continental United States, offering estimated potential of 500 to 1,000 Tcf with consistent increases as wells are brought online and additional information is gathered.[1] One key shale gas play identified as having promise for future development is the Devonian-aged Marcellus Shale of the Appalachians, with potential for 50 Tcf or more of technically recoverable gas.[2] While still in the early stages of development, this basin has the potential to be one of the largest gas plays in the US. Development of the Marcellus play has been made possible by recent advances in two key technologies—horizontal drilling and hydraulic fracturing.[3]

THE MARCELLUS SHALE

The Marcellus Shale extends from west-central New York on a northeast-to-southwest trend down into Pennsylvania, Ohio and West Virginia, with minor portions of the eastern side of the basin extending into Maryland and Virginia, Fig. 1. Interest in the Marcellus Shale was renewed in 2003 when Range Resources-Appalachia, LLC, drilled the first "new" Marcellus well in recent years and began experimenting with the techniques used in the Barnett.[4] This effort resulted in reported production in Pennsylvania from the Marcellus in 2005.[5] Since then, Marcellus Shale development has accounted for nearly 25% of the state's drilling permit applications, with 1,084 Pennsylvania drilling permits having been issued as of April 2009.[6] Development in other Appalachian states has been slower. For instance, the New York Department of Environmental Conservation has less than 38 completed wells targeting the Marcellus Formation in its current database.[7]

Current development practices in the Marcellus Shale involve the drilling of both horizontal and vertical wells. In the Appalachians, through mid-2008, wells completed in the Marcellus Formation have been predominantly vertical, but permitting activity is showing an increasing trend in the numbers of horizontal well permit applications.[5] For the Marcellus Shale, a vertical well may be exposed to as little as 50 ft of formation while a horizontal well may be developed with a lateral wellbore extending 2,000 to 6,000 ft within the 50- to 300-ft-thick formation. The increase in reservoir exposure represents one advantage horizontal wells have over vertical wells. Other advantages of horizontal wells include reduced surface disturbances resulting from well pads, roads and pipelines, as several horizontal wells can be placed on multi-well pads for a less intrusive impact to the surrounding area. Based on discussion with industry in the area, it appears that there will continue to be a combination of both vertical and horizontal wells developed in the Marcellus, although horizontal wells are expected to become the predominant drilling and completion method for the play.

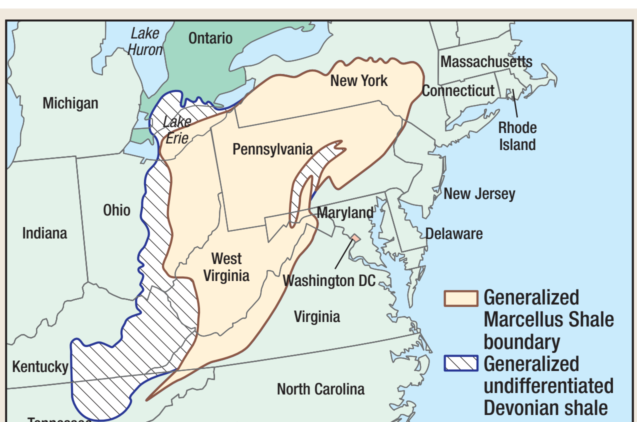

Fig. 1. Map of the Marcellus Shale.

FRAC FLUIDS AND ADDITIVES

A critical component of hydraulic fracturing, slickwater fracturing fluids are water-based fluids mixed with friction-reducing additives, which facilitate the pumping of these fluids at higher rates and pressures. Figure 2 shows a relational breakdown of the volumes of additives in a hypothetical 2.5 million-gal fracture treatment that would be comparable to a Marcellus Shale horizontal well treatment. Water is the primary component, making up 96.0% of the fluid with 3.57% being proppant, leaving only 0.43% as additives. Twelve additives were used on this particular fracture stimulation, but the number of additives can vary for each treatment, as additives are only added when the conditions of the formation require them for the well's success.[8]

Fracturing fluids require the use of multiple additives that serve different functions specific to the well undergoing the stimulation. Unique challenges such as scale buildup and bacteria require specific additives to prevent degradation of well performance. Well characteristics, formation properties and fracturing fluid compositions are a few of the criteria used to select the most appropriate additives for the stimulations.

Table 1 provides a summary of common fracture fluid additives, their main components, and the usual uses in the field and elsewhere for those compounds. The table illustrates that while there are a variety of different additives used in fracturing fluids, these additives are also contained in common products that people encounter in their daily lives. Service companies are also working to develop even more environmentally friendly fluids, such as using hydrochloric acid formulations that more easily break down into simple salts.[9]

WATER AVAILABILITY, FLUID HANDLING AND DISPOSAL

Drilling and fracturing a typical horizontal shale gas well is estimated to require 3–4 million gal (71,000–95,000 bbl) of water.[10] While this volume is not trivial, it is a small percentage (less than 0.1% to 0.8%) of the total water consumed by industry in any particular shale gas development region.[11]

As public concern over water usage increases in communities in shale gas basins, Marcellus operators are assessing possible supplies for water, including surface water, private water sources, municipal water, water supplies from groundwater and reused produced water. A study conducted by the Appalachian Shale Water Conservation Management Committee in 2008 identified surface water withdrawals as the primary source (60–70%) of the total water demand for drilling and completion activity in the Marcellus Shale Basin.[12] The Susquehanna River Basin Commission (SRBC) has noted an increase in applications for water withdrawals, mostly due to the oil and gas activity in the Marcellus Shale, and as such has triggered an administrative Approval by Rule regulation adopted in 2006 for projects using water "obtained solely from public water supply systems."[13] The agency's executive director also issued a Notice of Determination that all gas development in the Marcellus or Utica Shale Formation that involved the withdrawal or consumptive use of water was subject to review and approval through the SRBC regardless of regulatory thresholds.[13] However, water usage for drilling and completion in the Marcellus Shale (projected at 8.4 million gal per day) is dwarfed by area power generation demand of 150 million gpd.[12]

Additionally, the Pennsylvania Department of Environmental Protection, in an effort to ensure that environmental antidegradation practices are used to protect surface waters, is requiring operators to submit a Water Management Plan with drilling permit applications identifying water sources to be used, with safe yield calculations for surface water withdrawals for each well.[12] Operators are likely to deal with a variety of water regulatory agencies as oil and gas development increases in the Marcellus Shale.

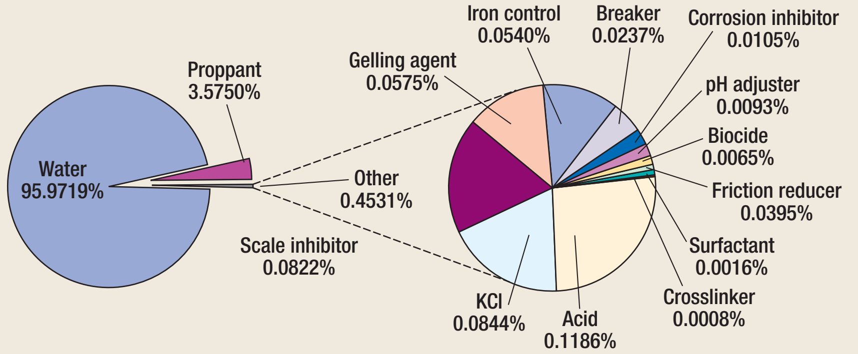

Fig. 2. Volumetric breakdown of a fracture treatment typical of the Marcellus.

TABLE 1. Fracturing fluid additives, main components and common uses

Additive type	Main component(s)	Purpose	Common use of main component
Diluted acid (15%)	Hydrochloric acid or muriatic acid	Help dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant to sterilize medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed breakdown of the gel polymer chains	Used in hair coloring, as a disinfectant, and in manufacturing of household plastics
Corrosion inhibitor	N, n-dimethyl formamide	Prevents corrosion of the pipe	Used in pharmaceuticals, acrylic fibers and plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps and cosmetics
Friction reducer	Polyacrylamide Mineral oil	"Slicks" the water to minimize friction	Water treatment and soil conditioner Makeup remover, laxatives and candy
Gel	Guar gum or hydroxyethyl cellulose	Thickens the water in order to suspend the sand	Cosmetics, toothpaste, sauces, baked goods and ice cream
Iron control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavoring in food and beverages
KCl	Potassium chloride	Creates a brine carrier fluid	Low-sodium table salt substitute
Oxygen scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH adjusting agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Used in household cleansers, de-icer, paints and caulk
Surfactant	Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant and hair color

Note: The specific compounds used in a given fracturing operation will vary depending on company preference, source water quality and site-specific characteristics of the target formation. The compounds shown above are representative of the major compounds used in hydraulic fracturing of gas shales.

Other public concerns revolve around the chemical properties of fracturing fluids or additives and their effects on public health, since recent reports have circulated identifying some of the agents used in hydraulic fracturing.[14] Since then, increasing public inquiry on the possibility of migration of fracturing fluids into underground drinking water aquifers is generating regulatory scrutiny and study of the issue.[15]

Water and fluid handling. Shale is a natural barrier to the vertical migration of fluids and is documented as confining layers to vertical migration of oil and gas. There are multiple shale zones present between the Marcellus Shale and shallow groundwater zones in much of the anticipated development area, which provides protection of groundwater resources from the hydraulic fracture treatments used to develop the Marcellus. In some parts of the Marcellus production area, there is as much as 7,000 ft of sedimentary rock strata, including thousands of vertical feet of shale, between the Marcellus and the shallow groundwater system.

The casing and cement programs required by oil and gas agencies are designed to ensure that drilling and construction of a gas well protects potential sources of drinking water. Analysis of the protection provided by casings and cements was presented in a series of reports and papers prepared for the American Petroleum Institute in the 1980s.[16,17] These investigations evaluated the level of corrosion that occurred in Class II injection wells, which are used for routine injection of water associated with oil and gas production. The research resulted in the development of a method of calculating the risk that fluids injected into Class II injection wells could result in a discharge of fluids that could reach an Underground Source of Drinking Water (USDW). The Appalachian Basin was ranked as having a minor potential for corrosion because only a few instances of casing corrosion had been reported by oil and gas agencies.

The analysis was then limited to those basins in which there was a possibility of casing corrosion.[17] For those basins, it can be correlated that—in a modern horizontal well completion in which 100% of the USDWs are protected by properly installed surface casings (and for geologic basins with a reasonable likelihood of corrosion)—the probability that fluids injected at depth could reach a USDW would be between 0.00002 per well-year (one well in 200,000) and 0.00000002 per well-year (one well in 200 million) if these wells were operated as injection wells. This analysis does not account for the fact that hydraulic fracturing of shale gas wells typically is done over a couple of days to one week. The Appalachian Basin was not identified as having a reasonable likelihood of corrosion, so the risk probability is likely lower than that presented above.

The API study also included an analysis of wells that had been in operation for numerous years, accounting for what are likely many variations in applied technologies and regulations. It is expected that the probability of groundwater being impacted by the pumping of fluids during hydraulic fracture treatments of newly installed wells with a high level of monitoring would be even less than 0.00000002.

The potential for hydraulic fracturing and Marcellus Shale development activities to impact surface water has been reduced by operator and service company practices over recent years, including the transition toward use of water-based slickwater fracturing fluids, which have fewer additives than cross-linked gel. Additionally, service companies performing hydraulic fracturing are designing systems to contain fracturing fluids within closed loops that would keep all additives, fracturing fluids, mixing equipment and flowback water within a storage tank, service truck or flowline.[18]

Disposal. After a hydraulic fracture treatment, when the pumping pressure has been relieved from the well, the water-based fracturing fluid begins to flow back through the well casing to the wellhead. This produced water consists of spent fracturing fluids and, in some cases, dissolved constituents from the formation; the dissolved constituents vary from one shale play to the next or even by area within a shale play. Produced water from shale gas can vary from fresh (less than 5,000 ppm total dissolved solids) to varying degrees of salinity (5,000–100,000 ppm TDS).[10]

The disposal of flowback and produced water is an evolving process in the Appalachians. The volumes of water that are being produced as flowback water are likely to require a number of options for disposal that may include municipal or industrial water treatment facilities (primarily in Pennsylvania), Class II injection wells, and on-site recycling for use in subsequent fracturing jobs.

In most shale gas plays, underground injection has historically been preferred. In the Marcellus play, this option is expected to be limited, as there are few areas where suitable injection zones are available. If such is not locally available, it may be possible to transport the produced water to a more distant injection site. Injection disposal wells are permitted under the federal Safe Drinking Water Act Underground Injection Control (UIC) program for the states of New York and Pennsylvania; in the case of state primacy, such as Ohio and West Virginia, the program is administered under equivalent applicable state programs. UIC programs are a stringently permitted and monitored process with many environmental safeguards in place.

Produced water treatment may be feasible through either self-contained systems at wellsites or fields, municipal waste water treatment plants or commercial treatment facilities. With an estimated apex of 8.4 million gpd required for oil and gas development in the future, and assuming less than 50% of that amount will require disposal as flowback or produced water from wells, about 95,000 barrels of water per day could require treatment before discharge to surface waters.[12] The availability of municipal or commercial treatment plants may be limited to larger urban areas where treatment facilities with sufficient available capacity already exist; as in underground injection, transportation to treatment facilities may or may not be practical.[5] As of this writing there are plans to construct commercial wastewater treatment facilities specifically for gas shale-associated produced water in some US locations.[19] However, as injection well disposal options appear increasingly limited in the Marcellus, operators and regulatory agencies are evaluating what treatment requirements would be necessary to return flowback or produced water to reuse by operators or to allow for discharge to surface waters by National Pollutant Discharge Elimination System permit. Those requirements center primarily on reducing TDS and concentrations of contaminants such as benzene, oil and grease, and suspended solids.[12]

A number of treatment processes are being evaluated and studied for effectiveness in other shale gas plays. In the Barnett Shale, the Texas Railroad Commission approved and Fountain Quail Water Management tested a water distillation process that allows reuse of 80% of the produced water in that region. As of April 2008, 5.7 million barrels of flowback water (and produced water) have been processed to recover 4.5 million barrels of water for reuse in operations.[20] Additional studies are proceeding to determine the minimum water quality necessary for successful hydraulic fracturing operations; recycling produced water could alleviate issues associated with water withdrawals from regional sources and disposal concerns in communities.[11]

CONCLUSIONS

Hydraulic fracturing and horizontal well completions appear to be effective for development of Marcellus Shale gas, although there have only been a few wells drilled to date. Advances are being made in the design of fracturing programs to develop more efficient ways to create additional flowpaths to the wellbores, and these advances are targeting extensive design and analysis of fracture treatments including simulators, microseismic fracture mapping and tilt measurements.[2] Production economics directly hinge on improving gas production by optimizing fracture development and ensuring that fracture propagation is limited to the target formation and does not extend into surrounding wet formations.

The potential for impacts to surface water and groundwater quality from Marcellus Shale development is expected to be minimal because of the regulatory requirements from state oil and gas agencies involved and the practices operators are implementing to ensure that fluids are contained. In addition, the thick sequence of Devonian-aged shales overlying the Marcellus acts as a series of confining layers to prevent the vertical migration of fracturing fluids toward groundwater systems. **WO**

LITERATURE CITED

1 Halliburton Energy Services, "U.S. shale gas: An unconventional resource: Unconventional challenges," white paper, 2008.

2 Engelder, T. and G. G. Lash, "Marcellus Shale play's vast resource potential creating stir in Appalachia," *The American Oil & Gas Reporter*, 52, No. 6, May 2008, pp. 76–87.

3 Matthews, H. L. and M. Malone, "Stimulation of gas shales: They're all the same … right?" SPE 106070 presented at the SPE Hydraulic Fracturing Technology Conference, College Station, Texas, Jan. 29–31, 2007.

4 Walser, D. W. and D. A. Pursell, "Making mature shale gas plays commercial: Process vs. natural parameters," SPE 110127 presented at the Eastern Regional Meeting, Lexington, Kentucky, Oct. 17–19, 2007.

5 Harper, J. A., "The Marcellus Shale: An old "new" gas reservoir in Pennsylvania," *Pennsylvania Geology,* 28, No. 1, Spring 2008, pp. 2–13.

6 Pennsylvania Department of Environmental Protection, Bureau of Oil and Gas Management, Weekly workload report for the week of May 4–8, 2009, http://www.dep.state.pa.us/dep/deputate/minres/oilgas/new_forms/marcellus/Reports/WEBSITE%20Weekly%20Report%20for%20Week%20Ending%2005-08-2009.doc accessed May 14, 2009.

7 New York Department of Environmental Conservation, New York's Oil & Gas Database, http://www.dec.ny.gov/cfmx/extapps/GasOil/ accessed Sept. 2, 2008.

8 Kaufman, P., Penny, G. and J. Paktinat, "Critical evaluation of additives used in shale slickwater fracs," SPE 119900 presented at the SPE Shale Gas Production Conference, Irving, Texas, Nov. 16–18, 2008.

9 Parshall, J., "Barnett Shale showcases tight-gas development," *Journal of Petroleum Technology,* 60, No. 9, September 2008, pp. 48–55.

10 Satterfield, J. et al., *Managing Water Resource's Challenges in Select Natural Gas Shale Plays,* Chesapeake Energy Corp., 2008.

11 US Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, *Modern Shale Gas Development in the United States: A Primer,* April 2009, http://all-llc.com/pdf/ShaleGasPrimer2009.pdf accessed April 22, 2009.

12 Gaudlip, A. W., Paugh, L. O. and T. D. Hayes, "Marcellus Shale water management challenges in Pennsylvania," SPE 119898 presented at the SPE Shale Gas Production Conference, Fort Worth, Texas, Nov. 16–18, 2008.

13 Beauduy, T., "Accommodating a new straw in the water: Extracting natural gas from the Marcellus Shale in the Susquehanna River Basin," presented at the Pennsylvania Bar Institute Environmental Law Forum, March 12, 2009.

14 The Endocrine Disruption Exchange, "Analysis of chemicals used in natural gas production," Dec. 6, 2008, www.endocrinedisruption.org.

15 New York State Department of Environmental Conservation, "Final scoping document for DSGEIS on well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus Shale and other low-permeability gas reservoirs," 2009, http://www.dec.ny.gov/energy/47554.html accessed May 12, 2009.

16 Michie & Associates, "Oil and gas water injection well corrosion," prepared for the American Petroleum Institute, 1988.

17 Michie & Associates, "Evaluation of injection well risk management potential in the Williston Basin," prepared for Underground Injection Practices Council Research Foundation, 1989.

18 New York Department of Environmental Conservation, Division of Mineral Resources, *Final Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program,* 2003.

19 Pennsylvania operators and service industry personnel, personal interviews, October 2008.

20 Arthur, J. D., Bohm, B., Coughlin, B. J. and M. Layne, "Evaluating the environmental implications of hydraulic fracturing in shale gas reservoirs," on ALL Consulting website, 2008, http://all-llc.com/shale/ArthurHydrFracPaperFINAL.pdf accessed April 27, 2009.

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