

Trip Report for Field Visit to Fayetteville Shale Gas Wells

Environmental Science Division

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by
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Introduction

This report describes a visit to several gas well sites in the Fayetteville Shale on August 9, 2007. I met with George Sheffer, Desoto Field Manager for SEECO, Inc. (a large gas producer in Arkansas). We talked in his Conway, Arkansas, office for an hour and a half about the processes and technologies that SEECO uses. We then drove into the field to some of SEECO's properties to see first-hand what the well sites looked like.

Purpose of the Field Visit

In 2006, the U.S. Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) made several funding awards under a program called Low Impact Natural Gas and Oil (LINGO). One of the projects that received an award is "Probabilistic Risk-Based Decision Support for Oil and Gas Exploration and Production Facilities in Sensitive Ecosystems." The University of Arkansas at Fayetteville has the lead on the project, and Argonne National Laboratory is a partner.

The goal of the project is to develop a Web-based decision support tool that will be used by mid- and small-sized oil and gas companies as well as environmental regulators and other stakeholders to proactively minimize adverse ecosystem impacts associated with the recovery of gas reserves in sensitive areas. The project focuses on a large new natural gas field called the Fayetteville Shale.

Part of the project involves learning how the natural gas operators do business in the area and the technologies they employ. The field trip on August 9 provided an opportunity to do that.

Fayetteville Shale

Unlike more traditional oil and gas fields that hold hydrocarbons in porous rock formations, shale holds natural gas in a fine-grained rock matrix. Until recent years, most shale formations were not considered profitable areas for gas production. With new technology and elevated natural gas prices, companies have made the Barnett Shale play in north Texas one of the hottest production fields in the country. Encouraged by the success in the Barnett Shale, operators looked at other large shale formations. The Fayetteville Shale play spans much of the northern and central portions of Arkansas. The Fayetteville Shale ranges in thickness from 50 to 325 ft and ranges in depth from 1,500 to 6,500 ft. The Arkansas Oil and Gas Board shows the locations of all the gas wells in the Fayetteville Shale play on its Web site (<http://www.geostor.arkansas.gov/apps/aogc/index.htm>).

Area Visited during the Field Visit

During the August 9, 2007, trip, we drove through Conway and Van Buren Counties, located north and west of Little Rock. After leaving the town of Conway, which was heavily developed

with commercial activity, we drove mostly through rural and agricultural areas. Route 65 is a four-lane road leading north from Conway. After about 45 minutes, we exited onto two-lane paved roads, which make up the main road network in these areas. At times, we turned onto some of the numerous “county roads” that were unpaved and had dirt and gravel surfaces. An example is shown in Figure 1. Those county roads were not designed to accommodate heavy traffic of large trucks and other oil field machinery.



Figure 1 – View of typical “county road” that is the primary route used to get to gas well sites.

How Does SEECO Produce Natural Gas?

This section of the report describes the steps followed in producing natural gas. I did not personally observe all of the steps during the field visit. However, I did talk with Mr. Sheffer about how SEECO conducts each step in the process.

Leasing: The first step toward producing natural gas involves gaining access to the property under which the prospective natural gas resources are located and on which surface facilities will be located. Unless the operator owns the mineral rights for a piece of land, the company must lease the mineral rights from the owner. A lease is a legal agreement that allows the company to explore for and produce gas from a tract of land in exchange for paying royalties. Leasing does not require petroleum technology or fieldwork. Therefore, it is outside the scope of this project.

Seismic Surveys: Companies can make educated guesses about which tracts of land within a field hold recoverable natural gas. Before making large financial investments, however, they typically perform seismic studies that help in characterizing the size, shape, and depth of the formations most likely to hold recoverable natural gas. SEECO uses 3D seismic technology. When conducting a seismic study, contractors utilize trucks and helicopters to move equipment into the field and collect data. The contractors drill a grid of 20-ft-deep holes and place an explosive charge of 1 lb of dynamite into each hole. The charges are detonated under controlled conditions, and the resulting vibrations are detected by a network of seismic sensors.

SEECO has an in-house geophysical group to analyze the data collected in the field. Mr. Sheffer did not have detailed familiarity with seismic methods and technologies, but noted that I could have a further conversation with Mike Rhoads, the head of SEECO's geophysical department. During the field visit, we passed a seismic crew working in a field several hundred meters back from the road. We also observed several long cables crossing the road, which were connected to seismic sensors in fields on the opposite side of the road.

Mr. Sheffer noted that in some heavily wooded areas, SEECO's field teams would hand-cut trees and bushes to clear access ways for seismic lines rather than bulldozing. This is somewhat more labor intensive, but it creates less environmental impact.

Well Drilling: After the company has identified a desired location for a well, it obtains permits to drill a well and construct a reserve pit (a pit located next to the drilling rig to catch the drill cuttings, used drilling mud, rainfall, and other materials). Before drilling can begin, the company clears vegetation and constructs a pad for the drilling rig and other equipment used in preparing the well and an access road to get from the county road to the well site. SEECO pays a use fee to the landowner for disturbing an area of 500 ft by 500 ft, plus the area of the access road. In practice, SEECO generally clears only 300 ft by 250 ft for the pad and the reserve pit plus two adjacent smaller "rig ditch pits," which collect fluids that fall onto the footprint area beneath the rig. SEECO lines the pits with a plastic liner and covers the pad and access road with gravel. Figure 2 shows the gravel pad at a recently completed well site. Figure 3 shows the gravel access road, Figure 4 shows the reserve pit, and Figure 5 shows one of the adjoining rig ditch pits.

Next the well is drilled. Oil and gas wells are constructed with multiple nested concentric layers of pipe known as casing (an entire length of casing is known as a casing string). The top interval is drilled starting at the surface and has the largest diameter hole. After a suitable depth has been reached, the hole is lined with casing that is slightly smaller than the diameter of the hole. Then cement is pumped into the space between the wall of the drilled hole and the outside of the casing. Next, a smaller diameter hole is drilled to a lower depth. Another casing string is installed to that depth and cemented. This process may be repeated several more times. The final number of casing strings depends on the regulatory requirements in place at that location. It reflects the total depth of the well and the strength and sensitivity of the formations through which the well passes.



Figure 2 – Newly constructed well showing gravel pad.



Figure 3 – Gravel access road.



Figure 4 – Reserve pit.



Figure 5 – Rig ditch pit.

SEECO drills a relatively large diameter hole from the surface down to about a 40-ft depth. This is lined with large casing called conductor pipe; the conductor pipe is cemented in place. Next SEECO uses an air-drilling rig to drill a hole to about a 500- to 550-ft depth. Surface casing is installed and cemented in place. SEECO continues with an air-drilling rig to drill deeper until the hole is about 600 ft above the top of the shale.

At this point, SEECO moves in one of its larger conventional drilling rigs (according to Mr. Sheffer, the company has 11 of its own rigs in the area) to drill the horizontal section. The larger rig uses drilling mud to lift cuttings from the well, lubricate the drill bit, and to serve other functions. Using the larger drill rig allows SEECO to deviate the well (i.e., instead of drilling vertically, the well bore curves off at an angle). Figure 6 shows three diagrams of directionally drilled wells. Nearly all of SEECO's Fayetteville Shale wells are horizontal wells that reach out laterally thousands of feet. Initially, wells were constructed with 2,200 to 2,500 ft of lateral reach. More recently, the wells are completed out to 3,000 to 4,000 ft. SEECO also tries to drill multiple wells from a single well pad, thereby minimizing surface disturbances.

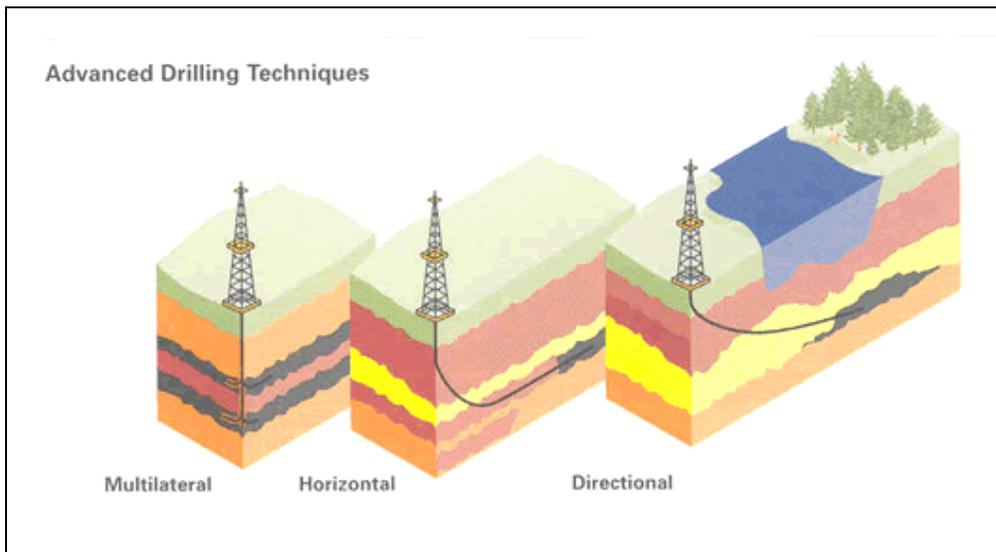


Figure 6 – Examples of directionally drilled wells. (Source: DOE 1999, “Environmental Benefits of Advanced Oil and Gas Production Technology,” DOE-FE-0385, U.S. Department of Energy, Office of Fossil Energy, Washington, D.C. Available at http://www.osti.gov/bridge/product.biblio.jsp?osti_id=771125)

Figure 7 shows a drilling rig in the process of drilling a well.



Figure 7 – Drilling rig.

Figure 8 shows a blue drilling motor on the pipe rack. Unlike the rest of the straight drill pipe in the background, the drilling motor has a slight curvature. It is placed on the leading end of the rotating drill string and gradually bends the well bore until the desired angle is reached.

Many of the horizontal sections of SEECO's wells are drilled using water-based muds (WBMs). When WBMs are used for drilling, the drill cuttings are placed in the reserve pit. At the end of the drilling job, the cuttings are stabilized with fly ash and then are buried in place after all liquids have been removed. Figure 9 shows a reserve pit that has been reclaimed by burial at the end of the drilling job. The used WBMs are disposed of using land application.

In some of the wells toward the eastern side of SEECO's leases in the Fayetteville Shale, the formations are more difficult to drill. There, SEECO uses oil-based muds (OBMs) to drill the horizontal sections. Because OBMs pose more environmental risk than WBMs, any wells drilled with OBMs use a closed system of tanks rather than putting muds and cuttings into a reserve pit. At the end of drilling a well with OBMs, the OBMs are recycled, and the cuttings are hauled offsite for disposal, typically at a municipal landfill, with permission from the landfill operator.



Figure 8 – Downhole drilling motor.



Figure 9 – Reclaimed reserve pit.

Preparing the Well for Production: A newly drilled well must be properly completed to allow gas to enter the well and move to the surface. In a well that has casing along the gas-producing section, holes or perforations (“perfs”) are made in the casing using small explosive charges or guns. The perfs allow gas to enter the well.

Because shale gas is held within a nonporous medium, it is necessary to fracture the shale so that gas has a conduit or pathway to move from the shale to a production well. The fracturing process (a “frac job”) injects water, sand, and other ingredients at very high pressure into the well. The high pressure creates small fractures in the rock that extend out as far as 1,000 ft laterally away from the well. The vertical extent varies but is related to the thickness of the shale layer. After the fractures are created, the pressure is reduced. Water can be removed from the well (“flow-back water”), but the sand grains remain in the rock fractures, effectively “propping” the fractures open and allowing the gas to move. Fracturing is a critical step in producing the Fayetteville Shale wells.

Previously, SEECO used nitrogen foam as its “fracking fluid.” It found that wells fraced in that way did not produce the fracture system the company hoped to achieve. SEECO now uses “slick water” — water with some surfactant additives to help the flow-back water return from the well at the end of the frac job.

SEECO conducts its frac jobs in stages. The length of the horizontal section of the well is divided into several sections by plugs. The outermost section is fraced first. First water is injected at increasingly higher pressure until a pressure chart shows that the bottom-hole pressure makes a sudden drop, indicating that the rock has fractured. At this point, sand is added to the injected water and the pressure is maintained until a desired dimension of fracing is completed.

The plug separating the last from the next-to-last section is sealed, and the frac job is continued for that section. The entire frac job may take a day and uses 50,000 to 80,000 bbl (2.1 to 3 million gallons) of water and 1 to 1.5 million lb of sand. Operators try to avoid hauling such a large volume of water across unimproved county roads. When local water supplies are available within a mile or two, SEECO will pump water for the frac job. SEECO is building a series of dams near its wells that can capture stormwater for future use as frac fluid. Figure 10 shows a temporary pipeline built to convey water from a pond to the well site.

Even without numerous tank trucks carrying water, the pad area at a well being fraced is crowded with heavy equipment. The service companies conducting the frac job will bring multiple engines and pumps, monitoring vans, frac tanks for making the frac fluid mixture and for capturing flow-back water, sand hauling trucks, and other support equipment. Figures 11 through 16 show a well in the midst of a frac job.

Immediately following completion of the frac job, the water used as part of the frac fluid begins to come back out of the well at a rate of 100 to 150 bbl per hour. It declines over time. This flow-back water is collected in 500-bbl frac tanks and is either reused or disposed of.



Figure 10 – Water pipeline conveying water for a frac job.



Figure 11 – Trucks lined up at the site of a frac job.



Figure 12 – One of several sand-hauling trucks in the center.



Figure 13 – A row of frac tanks.



Figure 14 – Sand storage tanks.



Figure 15 – The well being fraced is in the middle, with the pipe conveying the injectate. The two trucks beside the well are pumping units.



Figure 16 - The well being fraced is behind the white crane. The other wellhead near the middle of the picture was fraced on the previous day. In this case, two wells were constructed at the same well pad.

When the frac job is finished, SEECO brings in a coiled tubing rig to drill out the plugs that separated the sections of the horizontal leg of the well. Then a workover rig is used to install production tubing.

Water Management: Water is generated in three ways — ground water, flow-back water, and produced water. First, as the well is drilled with air drilling rigs, the borehole passes through shallow water-bearing formations. A substantial amount of water collects in the wellbore. SEECO is working with the Arkansas Department of Environmental Quality (ADEQ) to capture this water and treat it with an aluminum-based flocculant. If the chlorides concentration is less than 1,500 ppm, ADEQ allows the water to be applied to roads for dust control.

As mentioned in the previous section, a large volume of water is used to make up the frac fluid. Much of the water flows back out of the well immediately following the frac job. A significant volume comes out of the well at a slower rate over an extended period of time. Mr. Sheffer noted that the Fayetteville Shale generates very little produced water (i.e., water naturally in the shale rock along with the gas). The combined water flowing out of the well when the well is producing gas is a blend of flow-back water and produced water. If this production-phase water has a chloride concentration less than 5,000 ppm, it can be sent to a land application site. If the chloride concentration exceeds 5,000 ppm, the water must be transported to distant commercial disposal wells. The cost of disposing of the high-chloride water, including transportation can exceed \$6/bbl, a very high cost. SEECO has recently drilled some of its own water disposal wells

that are closer to its active sites. Active well sites generally have water storage tanks onsite. Figure 17 shows a water storage tank.



Figure 17 – Water storage tank at well site.

Well Production, Maintenance, and Closure: Gas initially flows to the surface by reservoir pressure. If necessary, later in the life of a well, SEECO plans to install plunger lift systems to produce the natural gas.

SEECO estimates that the life of these wells is 20 to 30 years. If production declines in a few years, SEECO would consider additional frac jobs to restimulate the well. When the well reaches the end of its productive life, SEECO plans to plug and abandon the well in accordance with the prevailing state requirements at that time.

Sending Gas to Market: Natural gas is produced at the wellhead (Figure 18). It moves to a metering station at the well site (Figure 19) and then is transferred to SEECO’s sister company that handles gas sales.

SEECO has constructed a series of underground gathering lines at each well site that connect to larger gas pipelines running along some of the county roads. Figures 20 and 21 show workers connecting sections of pipe in a trench near a site where active well drilling was occurring that day.



Figure 18 – Wellhead.



Figure 19 – Gas metering station at a producing well site.



Figure 20 – Worker connecting pipeline sections. Pipeline corridor can be seen in the background.



Figure 21 – Workers splicing plastic pipeline and connecting a junction line in the field.

Production Information

Within a few days following the field visit, the *Oil & Gas Journal* published a short article¹ giving some production statistics for Southwestern Energy Co., SEECO's parent company. Some of those statistics are provided in this section.

The company has run 145 mi² of 3D seismic through June 30 in the Fayetteville Shale play, and expects to reach 400 mi² of 3D seismic by the end of 2007. Southwestern averaged a net production of 105 MMcfd (million cubic feet per day) in the Fayetteville Shale during the first half of 2007. As of June 30, 2007, Southwestern has drilled and completed 303 producing wells; 246 of them are horizontal wells, and 219 were fractured using slick water fluid.

During the April–June 2007 quarter, Southwestern drilled and completed 62 wells in the Fayetteville Shale play. The average cost for these wells was \$2.9 million. The horizontal portion of the wells averaged 2,550 ft, but 10 of the wells had horizontal reaches greater than 3,000 ft. The average drilling time took 18 days. The last 10 wells completed with slick water frac jobs averaged initial production rates of 2.6 MMcfd.

¹ “3D Seismic Guides Arkoma Basin Fayetteville Play,” *Oil & Gas Journal*, August 13, 2007, p. 40.



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