FRACTURING
Rocks to Unlock New Oil

By Mark Crawford

Workers prepare a drill site and drill down to the strata of oil- and gas-bearing shale, several thousand feet below the surface.

When drilling approaches the shale, the drill is redirected horizontally to run along the center of the strata. The horizontal leg can run a mile or more in length.

With the easiest petroleum resources tapped, engineers needed better tools to reach hard-to-get oil and gas. Fortunately, the right technology was already in hand.
High-order explosives are lowered into the horizontal well to perforate the pipe and create fractures in the shale. Fluid is pumped under great pressure to push apart the fractures, and sand carried in the fluid props open the cracks. A well prepared this way can produce oil or gas for many years.
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Oil industry jargon is replete with terms that hark back to its seat-of-the-pants history. There are wildcatters and toolpushers and roughnecks and roustabouts. In the public imagination, “drilling for oil” is a roll of the dice where brawn matters more than brains.

“Fracking” is a bit of oilfield slang: it’s short for hydraulic fracturing, a technique that’s been in the oilman’s toolkit since the 1940s. But only in the past few years has hydraulic fracturing become a household word, thanks to its prevalent use in recovering oil and gas from deep shale deposits in the continental U.S.

The use of this technology has begun to change the way Americans think about their fossil fuel resources. In 2005, for example, 19 million cubic feet of gas was produced in the U.S., about the same amount the country produced in 1968, and the expectation was that the output would dwindle. By 2012, because of the boom in shale gas, the U.S. produced 25 million cubic feet, a new national record and more gas than any other country produced that year. Hydrofracturing is also increasingly being used to recover crude oil from shale deposits.

So what is it, exactly?

What we think of as hydraulic fracturing is actually a two-step process. First, the most time-consuming part is drilling into deep geological deposits and prepping the well. Then, over the course of three to ten days, water, sand, and chemicals are injected, under high pressure, into the well, fracturing the surrounding sedimentary rock and releasing trapped oil and gas. Particles of sand prop open the fractures—indeed, the particles are known in the industry as “proppants”—to enable the hydrocarbons to flow freely to the surface. Once a well has been hydraulically fractured, gas or liquids can be recovered for years.

“Fracking jobs have become bigger, more complex, and more common,” said Michael Economides, professor of chemical
and biomolecular engineering at University of Houston. “Probably more than 80 percent of America’s gas industry exists because of the success of hydraulic fracturing.”

**HOLDING TIGHT**

For more than 100 years, petroleum production was largely restricted to porous zones within geologic formations, especially the noses of folds, where extra porosity had been created. The oil and gas would migrate upward into these porous zones, but rise no further because the porous strata were capped by impermeable formations. The oil and gas could flow fairly easily across this zone, such that when a conventional vertical well pierced it, oil from as far as several hundred yards away could be drawn in.

Shale formations have long been known to contain oil and gas. But shale is not as permeable as other rocks and the fluids are tightly held. Any single conventional vertical well in shale generally isn’t able to draw in much of that oil and gas, so extracting the oil from a shale formation would require many closely spaced wells that it becomes economically infeasible to exploit.

That oil and gas stayed out of reach until the 1980s, when oilman George P. Mitchell, after 20 years of work, found a way to get at the resources locked tightly in the shale. “As a result,” Economides said, “shale rock has been transformed from being seen as a barrier rock between lachuster formations to becoming a target rock that contains massive quantities of trapped gas.”

Mitchell successfully combined two existing oilfield techniques. The first of these was horizontal drilling, which has been around for decades. Instead of piercing the layer of shale like a spike through a sheet of plywood, the drilling pipe is redirected underground until it follows the center of horizon, making continuous contact with the oil-bearing rock. Today, horizontal wells can extend up to a mile or more from the vertical part of the well. In fact, multiple horizontal wells can be drilled from the same wellhead, on the same site, minimizing surface disturbance.

This remarkable feat is possible because of “precision guidance systems, real-time imaging, sensors that can monitor and control a drill bit a mile or more underground, nanotechnology, advanced materials that make the drill bit possible, and a whole lot of computing technology to analyze the seismic results and other information as it comes in,” Economides said. “Rather than the hit-and-miss vertical wells drilled by wildcatters, we can often ‘see’ what we want and arrive within centimeters of the target, after miles of drilling.”

Drill steel is surprisingly flexible—all it takes is a short radius of 20 to 45 feet to start a horizontal well from the bottom of a vertical well. Increasingly sophisticated rotary steerable systems, combined with logging-while-drilling tools, help engineers accurately steer the well path in real time to keep it within the target formation. These tools include devices that transmit resistivity measurements and high-resolution images to the operators at the surface, which are useful for modeling the rock type and its mechanical characteristics, including how it will likely fracture. This data can also identify structural trends in the formation and how they may change ahead of the drill bit.

**BLASTING AND FRACTURING**

Mitchell combined horizontal drilling, which exposed more low-permeability shale to the well, with another long-known technology, hydraulic fracturing. But before hydraulic fracturing can happen, a team of specialists takes over the hole to perforate the drill casing in the zone of interest using high-order explosives and a downhole device called a perforating gun.

Blasting holes through steel casing, cement, and into surrounding rock is a high-precision affair that lasts only a few seconds, but is one of the most important stages of any “frac” job. A carrying device transports the carefully calculated and spaced explosive charges down the hole, where they are detonated at precise locations to create first openings through the pipe and then fracture patterns in the shale, which allow the oil- and gas-bearing fluids to flow from the rock into the wellbore and up to the surface.

Perforating guns are used to deliver tremendous high-velocity pressure waves that travel up to 7,000 m/s and exert as much as 103 GPa. According to Tony Smithson in the spring 2012 issue of Oilfield Review, “perforating guns are available in a variety of sizes and configurations. The most popular are through-tubing guns and hollow-carrier, or casing, guns. Hollow-carrier guns are larger than through-tubing guns and facilitate bigger charges, more
phasing options, and higher shot density,”

The type of gun selected is usually determined by the completion equipment being used on the job and the geologic properties of the reservoir.

“Engineers and scientists realize the importance of perforation for the long-term viability of the well,” Smithson added. “They continue to develop perforating techniques based on improvements in equipment design and deployment systems.”

A wellhead with control valves and connections to the production facilities is installed prior to hydraulic fracturing. These specially designed units separate the gas, oil, and water phases. By the time the fracking crew arrives, the rig and derrick have left the well site.

A typical hydrofracturing operation uses pump trucks to deliver a highly pressurized solution down the drill hole. The solution is 99.5 percent water and sand; the remaining half a percent is a proprietary brew of anti-bacterial compounds—bacteria can corrode pipes—and other additives intended to change the surface tension of the water to make it easier to pump down the hole, as well as recover. The high pressure forces the fluid into and expands the cracks created by the perforation, some of which may extend for hundreds of feet. The sand grains carried by the fluid become wedged in the fractures, keeping them open when the pumping pressure is reduced.

After fracturing is completed, the internal pressure of the geologic formation causes the fluids to rise to the surface, bringing along oil and gas, which are then separated. This “flowback water” is stored in tanks or pits prior to disposal or recycling.

UNDER PRESSURE

High pressures must be maintained to pump these fluids down the hole; the abrasive materials in the materials also cause considerable wear and tear on the pump, especially the valves at the fluid end.

Halliburton, one of the leading designers and manufacturers of hydraulic fracturing equipment, recently announced a next-generation pump called the Q10. This 2,000 bhp pump delivers a maximum pressure of 20,000 psi at rates varying from 2.7 to 18.9 barrels per minute. An in-line, five-cylinder design and mono-block fluid end is designed to provide improved durability—up to 14 times the life of older pumps, the company says.

Engineers continue to increase hydraulic fracturing efficiency by developing better multistage stimulation systems that enable treatment of many intervals along a horizontal wellbore with a minimum number of pull-outs, or even in a single continuous operation. The intention is to minimize downtime between hydrofracturing stages and reduce the amount of fluids needed.

One method consists of a valve containing a ball-and-seat system with a sliding sleeve that is sent down the hole.

“The ball seat is designed to capture a ball of a specific size that is pumped into the well,” wrote Isaac Aviles and Jason Baily in a recent issue of Oilfield Review. “When the ball lands in the seat, continued pumping causes pressure to build against the ball and seat. At a specified pressure, the ball-and-seat assembly moves downward, which opens a sleeve in the valve to expose the formation. The interval is then treated.”

MODEL BEHAVIOR

Many key advances in drilling and hydraulic fracturing have resulted from sophisticated modeling programs. “Hydraulic fracturing is really a study in applied fracture mechanics,” said Ron Dusterhoff, a mechanical engineer and Technology Fellow with Halliburton in Houston.

Dusterhoff is serious about modeling—his production enhancement group at Halliburton includes nine Ph.D. mathematicians. “Years ago, before the widespread use of hydraulic fracturing in shale, we were doing everything we could to avoid fracture complexity,” he said. “Now, with the shale boom, we are trying to create more complex fracture networks to release more oil and gas. This is an exciting field because we are looking at the intersection of fluid dynamics and complex fracturing dynamics.”

Mukul M. Sharma, professor of petroleum, geosystems, and chemical engineering at University of Texas in Austin, agrees that modeling has increased the precision of fracturing operations.

“Modeling allows us to see the interaction between multiple fractures in multiple wells in a single pad location through the use of tracers and microseismic data,” Sharma said. “Combine this with geomechanical mod-
Water usage is a critical issue for hydraulic fracturing. High-volume fracturing uses more than 100,000 gallons of hydraulic fracturing fluid, which is 99 percent water. Engineering and the picture becomes even clearer. Before we had these tools we had very little idea where the fractures were actually going. 

Open-hole wireline logging tools help predict shale rock characteristics, such as shale brittleness, as well as how flow rates affect fracture patterns or radioactive tracers and chemical tracers follow fracture patterns. Dan Snow, an independent consultant and project manager with extensive work in oilfield service remediation, believes tools that allow measurement and logging during drilling are critical components for success.

“For example, the Chandler Perforation Plot was developed in 2011 to determine what section of a lateral wellbore contains the highest concentrations of trapped hydrocarbons and what part contains noncommercial to marginal concentrations,” Snow said. “This knowledge lets the operator cut costs by selectively fracturing the zones that show a good response on the CPP, rather than the entire horizontal zone.”

With these advances in modeling and real-time measurement, Economides said, “operators can deliver just the right type of fracturing pressure, exactly where they want it, and repeat the process as needed, either in the same well, one that parallels it, or one that radiates out from the same central drill pad.”

**BETTER TOOLS**

Mechanical engineers play key roles in many aspects of hydraulic fracturing, especially the design of better down-hole tools, new materials, and improved numerical models. Sharma’s research group of about 40 people at the University of Texas is currently working on many aspects of shale oil and gas development. “These include better models for fracture growth, coupling of pore pressure effects with geomechanical effects, developing better methods for fluid placement, and novel methods for shale characterization,” Sharma said.

Research is a focus for D.V. Satya Gupta, global business development director at Baker Hughes’ Pressure Pumping Technology Center. “Research is also being conducted on drill-bit design, bifuel horsepower units, improved efficiency of operations including logistic solutions, and the ability to remotely operate fracturing equipment,” Gupta said. “We’d also like to improve abrasion resistance, high pressure/high temperature equipment design, and run pumps with line natural gas.”

Water usage is a critical issue for hydraulic fracturing. High-volume fracturing uses more than 100,000 gallons of hydraulic fracturing fluid, which is 99 percent water. The “flowback” water that returns is usually contaminated with salts, heavy metals, or naturally occurring radioactive compounds. David Burnett, a petroleum engineering professor at Texas A&M University and director of technology for the Global Petroleum Research Institute, is working on methodologies for safely recycling water produced from the well after fracturing and during hydrocarbon production.

“This includes developing non-damaging fract fluids and improved fracturing simulators to achieve better estimation of ultimate recovery—this will help reduce the environmental footprint of drilling and production operations,” Burnett said.

Economides is especially interested in improving productivity by developing tools that will help engineers and geologists better understand the near-wellbore state of stress in elastic and plastic rocks. This data, when integrated with complex well architecture and various production/injection approaches, will accelerate well production and consume fewer resources.

“Resource demand, American ingenuity, and modern technology, when combined with our engineering know-how, have made the United States the world leader in hydraulic fracturing,” Economides said. “It is difficult to say today what innovations will be made tomorrow, but one thing is certain—if the world wishes to fully use its oil- and-gas resources, it will go hand in hand with hydraulic fracturing.”

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