A new approach to drilling

Dr. William G. Buckman, Sr. and Zachary Pearl, Buckman Jet Drilling, Inc., USA and Dr. William C. Maurer, Maurer Engineering, USA, detail the production advantages that can be gained from the use of radial jet drilling.

Improved radial jet drilling (RJD) technology enables economical enhancements of both new and existing oil wells as indicated in recent worldwide publications.[1,2,3] This article describes the current radial jet drilling process, the improved jet bits, tubular goods, new fluids, equipment and innovative methods used for enhancing oil/gas wells. The jet bit (bit) is the most crucial component of the jet drilling system.

Dickinson et al.[4] in SPE 26348 used a procedure for reaming a large window in the casing and pushing the 1.25 in. coil tubing 25 to 150 ft into reservoirs to obtain enhancements of from 200 - 1000% in both light and heavy oil wells. Improvements depended on the reservoir and wellbore conditions. These jet drilled wells also had significantly less decline in production rates than traditional wells. With the development of better jet bits and flexible tubing that can withstand high pressures and can turn in a radius of less than 3 in., similar results can be achieved more economically.

Maurer also has considerable information on jet drilling in his book entitled "Advanced Drilling Techniques".[5]

RJD has a small footprint and is an environmentally friendly (totally green) method for drilling many horizontal micro-bore holes in the formation. While traditional horizontal wells cost from US$ 1 -10 million to drill and complete, the RJD costs typically vary from US$ 15 000 to US$ 75 000. A large percentage of reservoirs are carbonates. Advanced drilling fluids have recently been introduced that are environmentally friendly and are more effective than hydrochloric acid in dissolving carbonates to increase the permeability of the rock.

Buckman Jet Drilling, Inc. (BJD) has developed jet drilling systems that use coil tubing, as have most of the competition.[6] The company has also developed a relatively inexpensive system that is operator friendly and uses similar procedures to routine drilling. This system uses a workover rig and 1 in. diameter high pressure straight tubing that can withstand pressures of up to 20 000 psi to jet drill laterals in both soft and hard rock. This workover rig system can be employed worldwide by thousands of operators using their workover rigs.

The radial jet drilling system

Figure 1 illustrates the drilling apparatus for RJD. For producing wells with typical jackpump apparatus, the jackpump, rods and tubing and bottom hole pump are removed from the well. A diverter (or shoe) is then placed onto the bottom of the production tubing and lowered to the depth of formation to be jet drilled. This diverter has a curved path to enable the jet bit and flexible hose to turn from going straight down the tubing in the well and to approximately 90° toward the oil/gas formation. A jet bit is attached to a 10 000 psi or higher pressure rated flexible hose that has the flexibility to pass through a typical 3 in. radius diverter path. One end of this flexible hose is attached to a high pressure fluid filter, which in turn is connected to either coiled tubing or straight tubing pipe conveying the high pressure fluid from the top of the wellbore down to the filter. This tubing conveys the high pressure fluid from the high pressure pump at the surface and through the tubing with the fluid passing sequentially through the flexible hose, the jet bit and

Table 1. Jet bit penetration in 16% porosity, 69 md, 3500 psi Berea Sandstone

BJD jet bits	Flow (GPM)	Penetration rate (ft/hr)
834L	9	11
834C	16	37
High Flow (HF)	31	200
Xtreme Flow (XF)	37	900

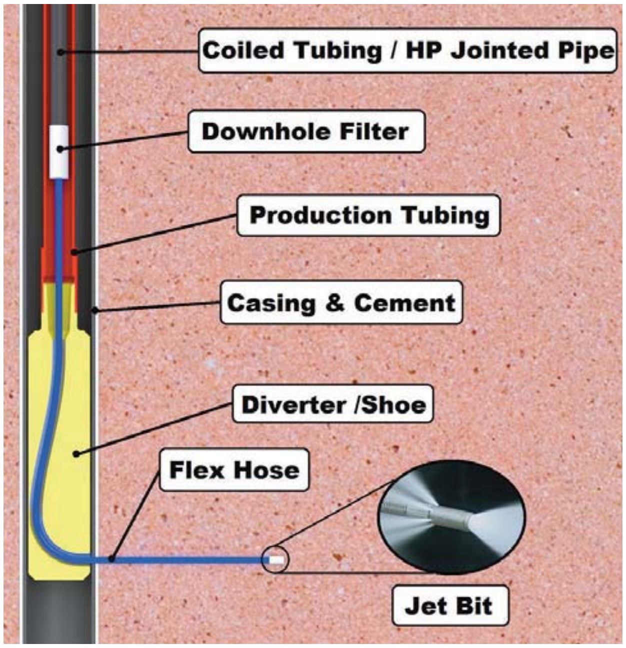

Figure 1. *Typical bottom hole assembly illustrating components used to create jet drill laterals.*

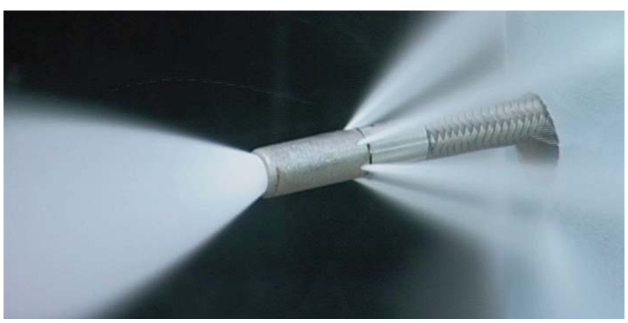

Figure 2. *Buckman Jet Drilling's jet bit nozzle under pressure.*

Figure 3. *Typical type cutting pattern from BJD jet bit.*

through the orifices of the jet bit to jet drill a lateral. An operator controls the jet drilling rate by controlling the rate that the conveying tubing is lowered into the top of the vertical well. Some wells contain steel casing and cement that must be penetrated before jet drilling. Other wells do not have steel casing at the zone of interest; these are referred to as uncased wells - they are much more readily jet drilled.

Jet bits and penetration rates

Figure 2 illustrates the Rock Scorpion™ jet bit. It produces a full cone vortex of high pressure fluid in the front that erodes and shears the rock to produce a hole in front with a diameter larger than the jet bit. Rear thrusters on the bit provide forward force propulsion (typically 10 to 50 lbf of thrust). These thrusters also cut deep slots or 'fins' into the rock which greatly increase the flow area to the vertical well. Figure 3 illustrates the hole produced by a jet bit in sandstone, which measures 7 in. from tip to tip. This bit is designed to operate at pressures up to 20 000 psi and at flow rates from 8 to 40 gpm. To employ the high pressures and flow rates, special flexible tubing and special proprietary short crimps are used to enable the 3 in. turn radius in the diverter.

Table 1 contains penetration rates of four different flow rate bits penetrating certified Berea Sandstone using 9000 psi bit pressure at flow rates of 9 gpm, 16 gpm, 31 gpm and 37 gpm. The Berea Sandstone has 16% porosity, 69 milliDarcies, and a compressive strength of 3500 psi. The penetration rate in certified Indiana Limestone sample with porosity of 11.5% and permeability of 0.39 milliDarcies is 250 ft/hr with the XF jet bit pressure of 10 000 psi.

Figure 4 illustrates the improved rate of penetration for the BJD medium flow rate bits versus pressure. Note the rapid drilling rate increases through our Berea Sandstone as the bit pressure is increased from 7000 psi to 12 000 psi. The high flow bit with a bit pressure of 12 000 psi penetrated this 6 in. thick Berea sandstone in one second, which corresponds to a penetration rate of 1800 ft/hr. Figure 5 shows the correlation between increased flow rate and increased penetration rate. New higher-flow jet bits are enabling economical advancement in tighter and harder formation types, which is reducing the run time required to create laterals.

The company has jet drilled core samples varying from 3.5% porosity Dolomite, Indiana Limestone (16% porosity and 10 mD), German Limestone cores (9.2% porosity 2.11 mD), Austin Chalk, heavy oil sandstone cores, Barnet Shale cores, Marcellus Shale cores and others.

Perforating and/or reaming of the casing

Advanced casing cutting and casing reaming techniques have been developed. Figure 6 is a photo of 1 in. holes drilled in a matter of minutes in thick P-110 casing using a PDM motor, flex shaft, and a milling bit (often referred to as a ballcutter). To use the Concept-5 process, the milling bit needs to be able to bore four 1 in. holes in one trip downhole. BJD has routinely milled 1 in. holes in both thin and thick steel casings from shallow depths to over 11 000 ft deep. Internal reaming capabilities that ream complete windows in the steel casing at the rate of about one inch per hour have also been developed. By using this technique, one can readily jet drill 10 laterals through one window into the formation.

Radial jet drilling system using coil tubing

For jet drilling zones at depths over 4000 ft, it is best to use coil tubing since it can be run in and out of the well rapidly, typically at rates of 100 ft/min. The coil tubing then conveys the high pressure fluid from the pump above ground down to the filter, which has its bottom connected to the flexible tubing. With high pressures and the coil bending at the top of the wellhead, the coil tubing will fatigue and have to be replaced after several cycles, depending upon the pressure and the amount of curvatures at the top of the wellhead. Using Flatpak™, where two coil tubings (duplex) are run at the same time, enables simple underbalanced jet drilling, monitoring of parameters such as temperature and pressure, and the mixing of fluids such as HCL and alkali to produce a hot acid to dissolve limestone and Dolomite (see Buckman patent #7 971 658). Unfortunately, the rental of coil tubing rigs can be very expensive and cost in excess of US$ 25 000 per day.

Radial jet drilling using 'macaroni' (straight pipe) tubing

A new jet drilling technique uses 1 in. diameter Macaroni tubing to replace coiled tubing as illustrated in Figure 7. The Macaroni tubing can be used with a PDM motor and milling bit to bore 1 in. holes in the casing. The tubing is retrieved to the surface and the flexible hose and jet bit are attached to the bottom of the tubing and then lowered so the bit passes downhole, through the diverter and drills a lateral. Due to the time it takes to trip the 1 in. tubing in and out of the wellbore, the Concept-5 system is employed to improve the efficiency. The basic operations are unchanged except the bottom of the tubing is connected to a high pressure transfer hose that travels with the pipe similar to traditional drilling techniques. A weight indicator is used on the workover unit to control the penetration rate into the formation. This method eliminates the high cost associated with coil tubing, lowers the upfront capital cost, significantly reduces the fatigue of high pressure tubing and provides higher pressures of up to 20 000 psi downhole to enable the jet bit to drill hard rock.

Fluids used in jet drilling

All jet drilling fluids pass through small jet bit orifices so a high pressure filter downhole is employed to prevent the fluid particles from plugging the orifices. Many different fluids and additives have been used over the past decades to jet drill. BJD uses 3% KCl in the fluid to reduce clay swelling in the reservoir and a friction reducer to reduce the pressure loss in the tubulars. Recent experiments with UltraFrac™ by Earthbornclean to replace hydrochloric acid have been very encouraging. It has performed as well or better than HCL, is earth friendly, safe and does not deteriorate the pumping equipment.

Some examples of enhancements provided by radial jet drilling

This jet drilling technology has been used by KOS Energy (now Petrobore Energy) in many uncased wells and hundreds of laterals have been performed. Many wells in Kentucky are shallow and uncased. One can readily, in one day, perform five levels of eight laterals at each level for a total of forty laterals in one day.

Some enhancements are as follows:

- Smith #1 Big Lime gas well was initially producing 10 000 ft^3 per day and zero oil. After jet drilling 16 laterals with lengths of about 30 ft each, the gas production increased to 120 000 ft^3 per day and 2 bbls. of oil. After choking the gas to 80 000 ft^3 with 220 psi of wellhead pressure, the well continues to produce.
- Russell #2 was an abandoned well in the 1980s producing only 1 bpd. After jet drilling 12 laterals with lengths of 40 ft each, the initial production went to 20 bpd and has since decreased to approximately 12 bpd.
- Barnes #4 was a tight Warsaw well. Initial production was zero bpd and after drilling 60 laterals with average lengths of 8 ft, the production was only 1 bpd.
- Tarter #2 was a Corniferous well without production. After drilling 16 laterals with average lengths of 12 ft, the production was 14 bpd.
- Carl Hill was a non producer. Twelve 12 ft laterals increased production to 20 bpd and then production declined to 12 bpd. Then an adjacent frac damaged all wells in that region.
- WES of Hays, Kansas. On December 10, 2012 a well in Rice County, Kansas was producing 7 bpd. After drilling three laterals using 660 gal. of Ultrafrac per lateral, the well initially produced 30 bpd and has now settled at current rate of 15 bpd.
- Shanghai Witsun reports enhancements of over 200% in the Shengli and Jiangsu oilfields in China.[7]

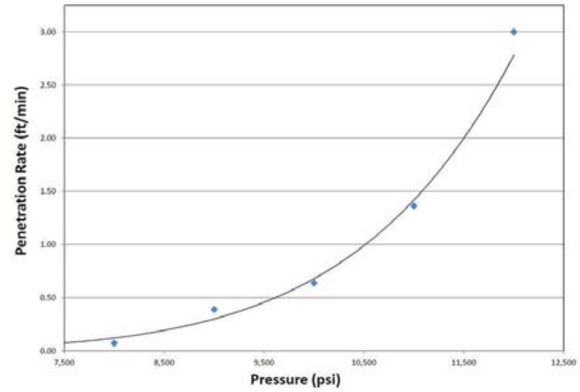

Figure 4. *This chart shows the relationship between penetration rates associated with jet bit pressure.*

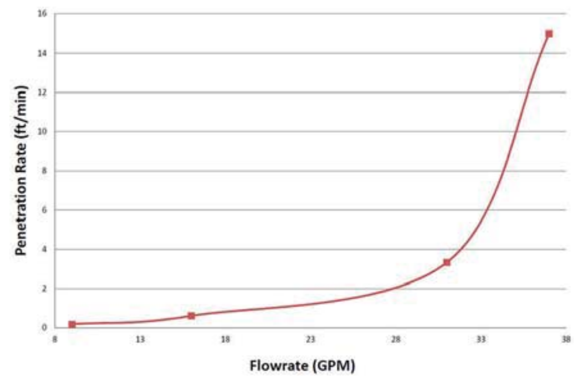

Figure 5. *This chart shows the relationship between penetration rates associated with jet bit flow rates.*

Conclusion

Improved RJD technology is enabling more economical enhancements of both new and older wells. OT

References

1. Cinella, Steven D.,; Kamel, Ahmed H.,"Low-cost radial drilling helps revitalize 40-year-old oilfield," Drilling contractor, May/June, 2013.

2. Elliott, Steve, “Coiled-tubing method drills laterals to improve oil production from a depleted reservoir,” *World Oil*, October, 2011.
3. Thomas, Mark, “Jetting technology improve production,” *E&P Magazine*, September, 2011.
4. Dickinson, Wade; Dystra, H.; Nordland, R.; Dickinson, Wade; “Coiled-tubing radials placed by water-jet drilling: Filed Results, Theory, and Practice,” SPE 26348, 68th SPE/ATCE, Houston, Texas, October 3 - 6, 1993.
5. Maurer, William C.; “Advanced Drilling Technologies,” Petroleum Publishing Co., 1980.
6. Landers, Carl; U.S. patent # 5,413,184, “Method of and apparatus for horizontal well drilling,” May 9, 1995.
7. Personal communication with Shanghai Witsun.

Figure 6. *A sample piece of 4 ½ in. casing with multiple 1 in. holes milled with the BJD case cutting system.*

Figure 7. *Typical workover rigs can now be used to deploy RJD technology.*