High Pressure Downhole Pump Jet-Assist Drilling

S. Veenhuizen (206-872-8500)
FlowDril Corporation
21414 68th Avenue So.
Kent, WA 98032

J. Duda (JDUDA@metc.doe.gov; 304-285-4217)
U.S. Department of Energy
Federal Energy Technology Center
3610 Collins Ferry Road
Morgantown, WV 26505

Introduction

The purpose of ultra-high pressure, jet-assist drilling is to increase the rate of penetration (ROP) in the drilling of deeper gas and oil wells where the rocks become harder and more difficult to drill. Increasing the ROP can result in fewer drilling days, and therefore, more economical drilling of gas and oil wells. To accomplish ultra-high pressure, jet-assist drilling requires a jet-assisted drill bit and a source of pressure. The source of pressure is an ultra-high pressure downhole pump (DHP®). In late 1993, FlowDril and the Gas Research Institute (GRI), based on FlowDril technology developed in pumping and sealing high pressure drilling mud, began development of a DHP. A first engineering prototype was designed, built and tested. Results of field experimentation with the first prototype were reported in Veenhuizen (1995) and Veenhuizen et al (1996).

To accelerate development and commercialization of the DHP technology for ultra-high pressure, jet-assist drilling, FlowDril, with the cooperation of GRI, contracted with the U.S. Department of Energy (DOE) in late 1994 to develop and test a second generation prototype. DOE recognizes the benefits of advanced technologies to the gas and oil industry, and as such, manages a portfolio of drilling-related research, development, and demonstration (RD&D) projects. The DOE's program is implemented by the Federal Energy Technology Center through its field office located in Morgantown, WV (FETC-MGN). These drilling-related projects support DOE's ultimate goal of facilitating development of the Nation's large natural gas resource base and maintaining market-responsive supplies at competitive prices. The RD&D program is highly coordinated with GRI activities and resources are leveraged when beneficial to the programmatic needs of both organizations. A more comprehensive treatment of DOE's oil/gas drilling-related RD&D was provided by Duda and Yost (1995). Much of the intangible cost of well drilling is time-sensitive, hence equipment, products, and technologies which increase ROP

Research sponsored by the U.S. Department of Energy's Federal Energy Technology Center, under contract DE-AC21-94MC31198 with FlowDril Corporation, 21414 68th Ave. So., Kent, WA 98032; telefax: 206-872-9660.

are core to DOE's program. Faster drilling equates to more efficient resource development and optimum use of capital. The DHP represents one such high-ROP technology.

Objectives

The objective of this project is to accelerate development and commercialization of a high pressure downhole pump, DHP, to be used for ultra-high pressure, jet assist drilling. As a means to accomplishing this objective, a second generation prototype of a DHP for drilling in 200 mm (7-7/8 inch) holes was designed, fabricated, tested in the laboratory, and tested downhole in the field.

Approach

The approach to ultra-high pressure (UHP), jet-assist drilling utilizing a DHP is depicted in Figure 1. The DHP is located in the conventional drill string just above the jet-assisted drill bit. The power to drive the DHP is provided from the mud stream pumped downhole through the drill string. Conventional flow rates are used but pressure at the rig pump is increased between 10.3 MPa (1,500 psi) and 13.8 MPa (2,000 psi) above typical surface pressures. The DHP produces about 75 l/min (20 gpm) at pressures up to about 207 MPa (30,000 psi). This allows a high-velocity jet of drilling mud at the bit to be directed at the bottom of the hole to assist the mechanical action of a tri-cone insert bit. The size of the DHP is about the same as a conventional drill collar and it is handled by the rig in a manner similar to a drill collar.

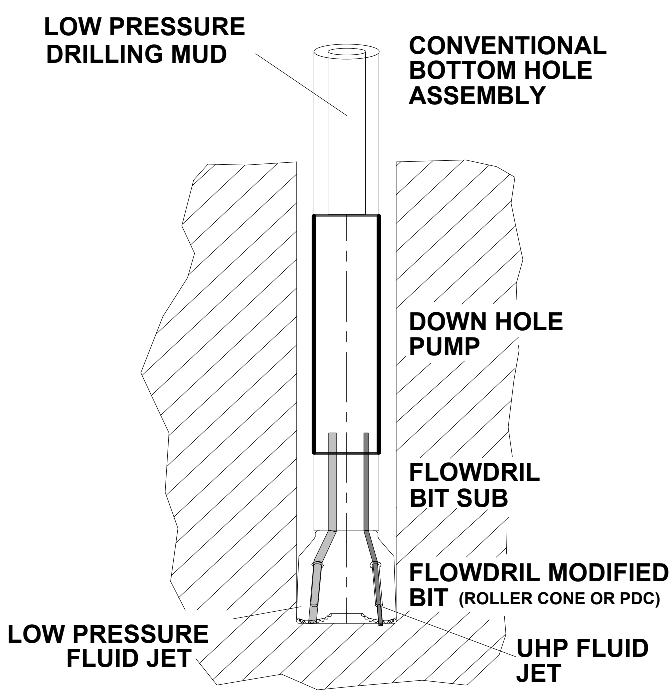

Figure 1. Jet Assist Drilling with a Downhole Pump (DHP®)

Project Description

The type of pump is an intensifier pump. The concept, illustrated in Figure 2, utilizes a reciprocating intensifier style high pressure pump, an accumulator to maintain the UHP jet when the pump changes direction, a self-cleaning filter for the UHP fluid, and the necessary valving to valve the drive fluid within the pump. With the by-pass valve closed, the drive fluid passes through the main four-way directional control valve and is directed to either the "A" side or the "B" side of the low pressure drive pistons. The larger diameter drive pistons and the smaller diameter high pressure plungers are connected and form the main assembly that reciprocates back and forth in the pump. When the drive piston/plunger assembly reaches the end of its travel, a trigger mechanically activates the pilot valve, which in turn shifts the main valve, re-directing the drive fluid from "A" to "B", or "B" to "A", driving the drive piston/plunger assembly in the opposite direction. When the by-pass is closed, all of the fluid is directed into the drive section of the DHP, except that which is drawn off through the self-cleaning filter to become the high pressure fluid output of the pump. When the by-pass valve is open, fluid passes through the pump to the bit, by-passing the pumping section of the DHP. The output pressure of the DHP is determined by the drive fluid pressure and the intensification ratio, i.e., the ratio of the effective area of the larger diameter drive pistons to the smaller diameter plungers.

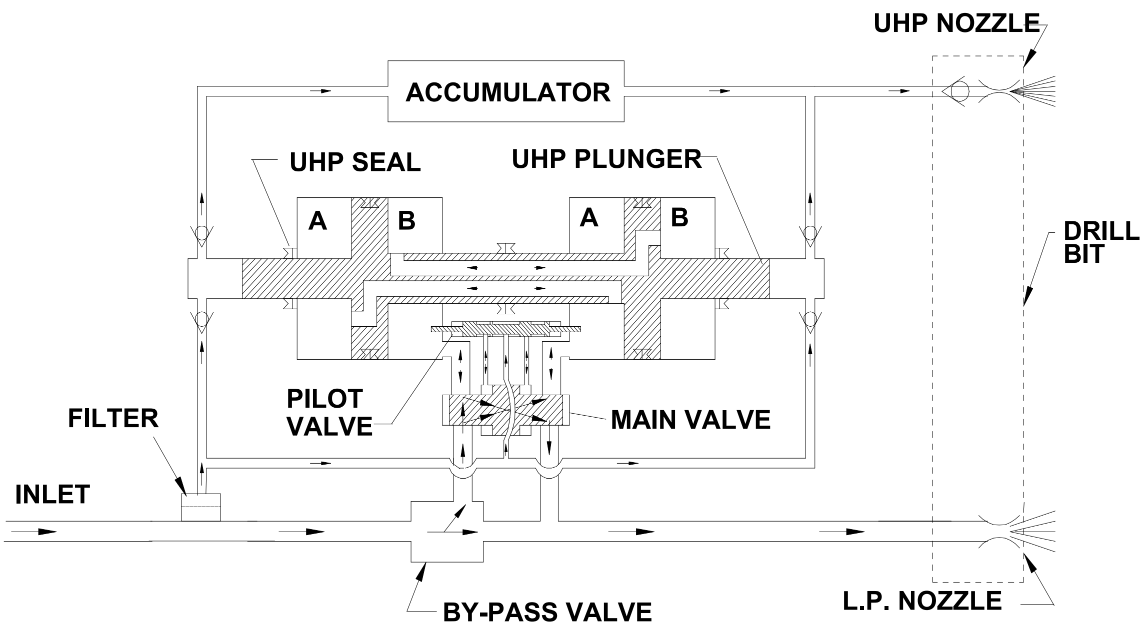

Figure 2. FlowDril DHP Concept.

Results

As mentioned previously, the size of the DHP is about the same as a conventional drill collar and is handled by the rig similar to a drill collar. Based on a DHP market analysis for vertical U.S. land drilling by Veenhuizen and O'Connor (1994), the DHP was sized for drilling 200 mm (7-7/8 inch) diameter holes. The DHP, as it was tested down hole in a field experiment in Norway, is shown being picked up on the drilling rig in Figure 3. Overall length, not including the drill bit, is 10 meters (33 feet). The top 1.8 meters (5 feet, 10 inches) is a fishing neck 159 mm (6-1/4 inch) in diameter. The remainder of the pump housing is 171.5 mm (6-3/4 inch) in diameter. A short bit sub, 0.45 meters in length, just above the bit, is 175 mm (6-7/8 inch) in diameter.

The first generation prototype was tested in the laboratory with laboratory drilling mud accumulating 168 hours of test time. It was also tested downhole in five field experiments, designated as FE-1 through FE-5, accumulating 72 hours downhole and achieving a 41-hour downhole test run on water. Results of the field experimentation with the first prototype were reported and discussed in Veenhuizen (1995) and Veenhuizen et al (1996).

Over 50 laboratory test runs were conducted, accumulating 480 hours of laboratory test time on the second generation prototype. A number of proprietary design improvements were introduced during laboratory testing to address mechanical strength and dynamic loading issues, low cycle fatigue, fabrication difficulties, and both drive fluid and UHP sealing issues. The second generation prototype was an improvement over the first prototype with better relative performance and improved hydraulic efficiency. At the conclusion of laboratory testing, the second prototype had achieved run times averaging 40 hours with laboratory drilling mud.

Over 75 hours of downhole test time were accumulated in five downhole field experiments, designated as FE-6 through FE-10, with the second generation prototype to evaluate design issues limiting downhole operating hours. In the last three of these field experiments, two DHPs were tested, an "A" pump and a "B" pump. The "A" pump was always considered the better pump and more representative of the status of the DHP technology as it was always assembled with newer and better components. The "B" pump was always the backup pump in case the "A" pump would not run for some reason; however, in each case the "B" pumps were also run downhole.

Downhole experiments FE-6, FE-7 and FE-8 were conducted in East Texas in the Travis Peak formation at depths between about 1,935 and 2,195 meters (6,350 and 7,200 feet). As described by Watson et al (1996), this formation starts at depths between 1,920 and 1,980 meters (6,300 and 6,500 feet) and is composed of laminated sections of shale, some limestone, sandy mudstones, muddy sandstones, and sections of very abrasive fine-grained sandstone. The average unconfined compressive strength is 69 to 103 MPa (10,000 to 15,000 psi) with peaks as high as 138 MPa (20,000 psi). As depth into the Travis Peak increases, the percentage of abrasive sandstone increases. Bit ROPs average about 4.6 m/hr (15 ft/hr) at the top of the formation and decrease with increasing depth.

Figure 3. DHP Being Picked Up on the Drill Rig in Norway.

Downhole experiments FE-9 and FE-10 were conducted in a test well operated by RF-Rogaland Research in Stavanger, Norway. The DHP tests were at a depth of about 1,250 meters (4,100 feet) in an abrasive granite formation with an unconfined compressive strength of about 220 MPa (32,000 psi). Typical bit conventional ROP was about 2.2 m/hr (7.2 ft/hr).

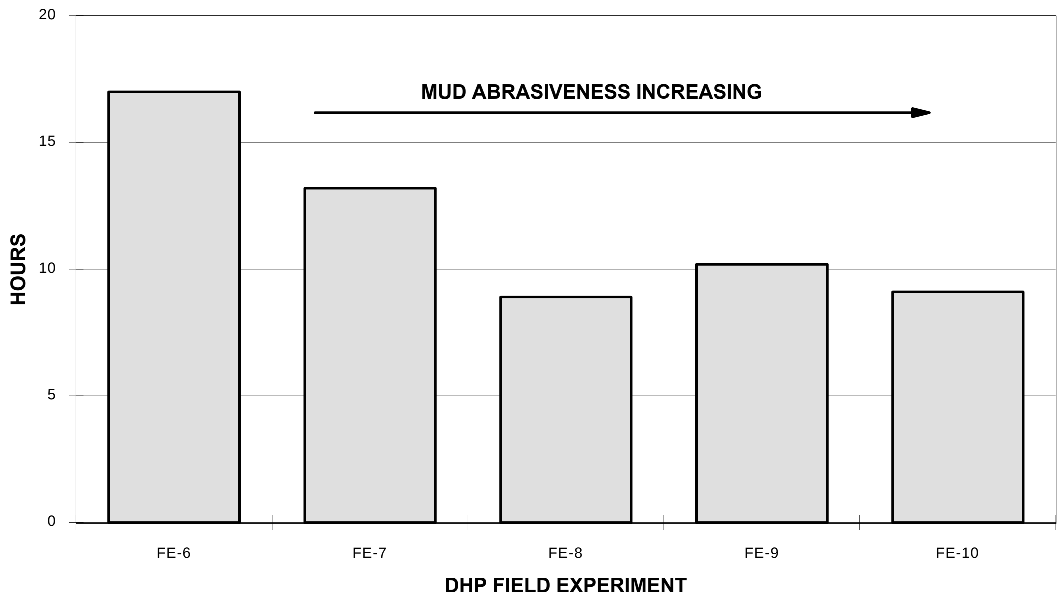

Figure 4. Second Prototype DHP Field Experiments.

Hours achieved in each of the downhole field experiments are shown in Figure 4. Failures downhole in FE-6 and FE-7 were due to an unreliable assembly procedure in the pump main valve in one case and over stressing the moving main valve spool assembly in the latter case. These failures were resolved with design changes that were introduced and confirmed through laboratory testing, concluding in the 40-hour laboratory test runs mentioned above. The failures limiting downhole pump life in the last three downhole experiments, FE-8, FE-9 and FE-10 were all due to fluid erosion within the DHP. Beginning with FE-8, it became apparent that the drilling mud in the field was much more abrasive than in the laboratory. As indicated in Figure 4, the field drilling mud became generally more abrasive with each successive field experiment, resulting in more severe erosion and more apparent abrasion.

The approaches being evaluated to address the fluid erosion and abrasion issues are more erosion-resistant materials and erosion-resistant coatings. It is believed, however, that to properly resolve the erosion and abrasion issues, several areas of the design of the DHP will require significant revision. As a result, it is planned to design, build and test a third prototype that is expected to be a pre-production prototype DHP.

Application

Testing and development of the DHP has been the focus of the down hole experiments with the DHP; however, there has always been an interest in the ROP benefit from UHP jet-assist of the bits. The drill bits used with the DHP have all been conventional, off-the-shelf, tri-cone insert bits to which a single UHP jet has been adapted. The bit shown in the rock in Figure 6 is the bit used in FE-10. It has a high pressure tube extended through the conventional mud jet port. The ultra-high pressure nozzle is in the nozzle cap at the end of the high pressure tube near the hole bottom. The ultra-high pressure jets produced by the nozzle have all been continuous, fully submerged, non-cavitating jets generally directed at the hole bottom near the gage of the hole. Nozzle exit diameters have generally been in the range of 1.6 mm (0.063 inch), requiring the nozzle to be placed near the hole bottom to be effective in cutting a kerf in the rock. As described by Veenhuizen, et al (1997), kerfing of the rock in the bottom of the hole is believed to be essential to the mechanism of high pressure jet-assist ROP enhancement.

Figure 5. Jet-Assisted Tri-cone Insert Drill Bit.

In East Texas, where FE-6, FE-7 and FE-8 were conducted, conventional rig standpipe pressures average about 13.4 MPa (1,950 psi). The bits are insert roller cones, IADC 537 in the upper part with either IADC 637 or IADC 747 bits in the lower part of the formation. They are normally equipped with one size 10 nozzle and two size 11 nozzles, resulting in 3 to 5 hydraulic horsepower per square inch (HSI). WOB is typically 20.5 tonnes (45,000 lb) and rpm is usually 45 to 50 rpm. Table 1 shows a comparison between conventional and UHP jet-assist drilling hydraulics as the DHP was operated during FE-7. The conventional bit has a pressure drop of 8.1 MPa at about 1140 l/min (1,180 psi at 300 gpm, or 4.2 HSI). With the DHP, most of hydraulic horsepower is directed to the UHP jet, resulting in a power density of about 5.2 HSI. To accomplish this, some of the conventional pressure drop is taken away from the bit, leaving only about 1.2 HSI for the conventional bit nozzles. The total across the UHP jet-assist bit is about 6.4 HSI.

Table 1.
DHP Jet-Assist and Conventional Hydraulics

	Conventional	Jet-Assist
Mud Pump Power (hhp)	343	497
Stand Pipe Pressure (psi)	1,960	3,420
Circulation Rate (gpm)	300	249
Pressure Losses (psi)	780	550
DHP Pressure Drop (psi)	-	2,458
UHP Pressure (psi)	-	27,400
UHP Flowrate (gpm)	-	16
Bit Pressure Drop (psi)	1,180	412
Bit Flowrate (gpm)	300	233
Bit HSI		
Conventional	4.2	1.2
UHP	-	5.2
Total	4.2	6.4

l/min = gpm x 3.786; MPa = psi ÷ 145; kw = hhp x 0.745

In each downhole experiment, offset conventional ROP data was obtained from a nearby well for comparison with the UHP jet-assist ROP. This comparison is shown in Figure 6 as a ratio of UHP jet-assist ROP to conventional offset ROP achieved in each of the field experiments FE-6 through FE-10 with the second generation prototype DHP. The type of bit used in each downhole experiment is indicated on the chart in the Figure 6. They include two F3's (IADC 537), an F57 (IADC 637) , an ATJ66 (IADC 647), and an F7 (IADC 737).

The F3H bit run in FE-6 was the same F3H bit run in FE-7. In FE-7 it was run with the nozzle positioned closer to the bottom of the hole and located through a different mud-jet port to better jet-assist the teeth on the bit. The F7 bit in FE-8 again had the UHP nozzle off bottom and was run before it was realized that alignment with the teeth on the bit was such a sensitive factor. Unfortunately the F7 was not tested in the laboratory drilling test facility prior to the downhole experiment, and difficulties with the DHP precluded full output pressure during most of FE-8, making a valid ROP assessment impossible. Both the F57 and the ATJ66D bits were tested in the laboratory prior to the downhole experiment and actually performed better downhole than in the laboratory. For those bits properly tested before the downhole experiments and when the DHP operated properly, FE-7, FE-9 and FE-10, the UHP jet-assist ROP was typically between 1.5 and 1.6 times the conventional ROP.

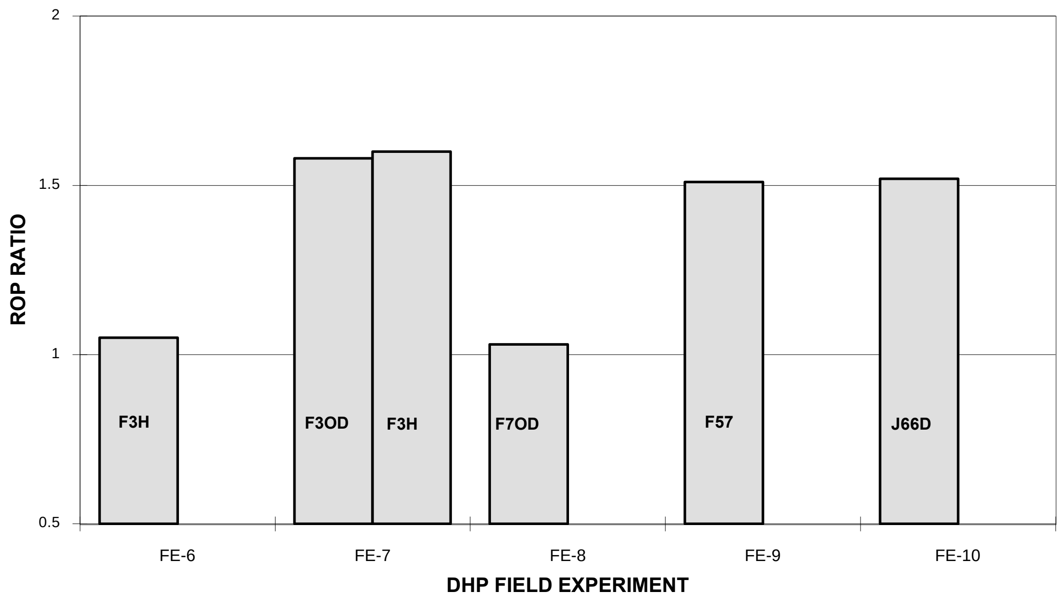

Figure 6. Field DHP ROP Ratios.

Future Activities

Although the UHP jet-assist ROP has been typically between 1.5 and 1.6 times the conventional ROP, an improvement in the UHP jet-assist ROP ratio would make the DHP jet-assisted drilling economics more favorable. Therefore, it is planned to increase the effort with the UHP jet-assisted bits to provide consistent ROP results and improve the UHP ROP ratio.

Laboratory test runs with the second prototype DHP have achieved 40 hours on laboratory drilling mud; however, the increased abrasiveness of the field muds has limited the downhole field runs to between 9 and 17 hours due to fluid erosion and particle abrasion. It is planned to address these technical design issues through designing, building, and testing a new pre-production prototype DHP.

Acknowledgments

COR John R. Duda, U.S. Department of Energy, Federal Technology Center, Morgantown, WV; contract DE-AC21-94MC31198; period of performance, 9/24/94-3/31/97.

References

Duda, J.R., and Yost, A.B., (1995), "DOE/Fossil Energy's Drilling, Completion, and Stimulation RD&D: A Technologies/Products Overview," SPE 30993, Eastern Regional Conference and Exhibition, Morgantown, WV, September 18-20.

Veenhuizen, S.D. and O'Connor, J.M., (1994) "Market Analysis: Downhole Pump for Jet-Assisted Drilling," Topical Report GRI-94/0176, Gas Research Institute, April.

Veenhuizen, S.D. (1995), "DOE/GRI Development and Testing of a Downhole Pump for Jet-Assist Drilling," Natural Gas RD&D Contractors Review Meeting, U.S. Department of Energy, Office of Fossil Energy and Southern University, Baton Rouge, LA, April 4-6.

Veenhuizen, S.D., O'Hanlon, T.A., Kelley, D.P., Duda, J.R., and Aslakson, J.K (1996), "Ultra-High Pressure Downhole Pump for Jet-Assisted Drilling," IADC/SPE 35111, IADC/SPE Drilling Conference, New Orleans, LA, March 12-15.

Veenhuizen, S.D., Kolle, J.J., Rice, C.C., and O'Hanlon, T.A., (1997), "Ultra-High Pressure Jet-Assist of Mechanical Drilling," SPE 37579, SPE/IADC Drilling Conference, Amsterdam, The Netherlands, March 4-6.

Watson, P.A., Welch, R.M., and Scott, D.E., (1996), "New Hard Formation Roller-Cone Bit Technology Improves Economics of Abrasive Travis Peak, Cotton Valley Wells," IADC/SPE 35114, IADC/SPE Drilling Conference, New Orleans, LA, March 12-15.