Improved ROP in Ultrahard Rock

Drilling the hard and very abrasive Bunter formation in northwest Germany has been a challenge for 40 years. Low rates of penetration (ROPs) and high tool wear are common. The full-length paper details the analysis of historical data and the combination of bits, motors, and other bottomhole-assembly (BHA) components to improve ROP. The combination of new impregnated bits, new downhole motors, and improved hydraulics was the basis for the improvement.

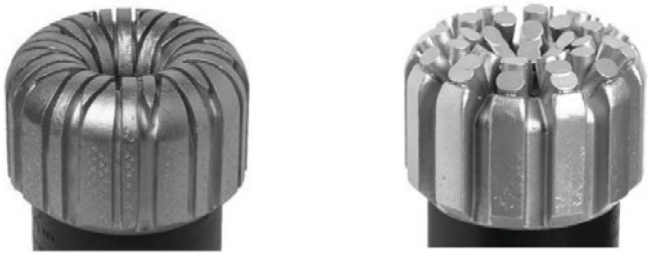

Fig. 1—Impregnated bit with continuous (left) and interrupted (right) cutting structure.

Introduction

The Bunter, a hard and very abrasive formation, typically at a depth of 8,000 to 12,500 ft, consists of layers of quartzitic sandstone and silificated claystone with a compressive strength of 30 to 50 ksi. In the past, typical ROPs in 12¼-in. sections were 3 to 6 ft/hr. In the 1970s and 1980s, 15 to 20 insert bits were required to drill the section and reaming was necessary as a result of undergauge bits.

In the 1990s, a research project was initiated and funded by the German drilling industry to improve ROP in ultrahard and abrasive formations. In the past, the Bunter was characterized by the lowest ROP, shortest bit life, and highest cost per foot. Increasing the depth of cut (DOC) of impregnated bits in the Middle and Lower Bunter was identified as having potential for improvement. DOC means the length that is drilled with one revolution of the bit. An increase in DOC can be achieved by a decrease in overbalance or an increase in the amount of power available for drilling the rock. To analyze the key parameters, drilloff tests or drilling tests at fixed drilling parameters were conducted and plotted into Bingham diagrams.

Within the German drilling industry, two approaches to increase ROP have been chosen—use of downhole turbines and use of high-speed downhole motors in combination with improved hydraulics made possible by larger-inside-diameter drillpipe.

The full-length paper details results from downhole-motor runs with impregnated bits. All results are from 12¼-in. bits because this is the most common bit size used in Germany for the Bunter formation.

Rotary Speed. Until 1997, the standard for high-speed downhole motors was 400 rev/min at 790 gal/min (360 hp). In 1997, a 9½-in. downhole motor was tested in Germany at 780 rev/min at 849 gal/min (515 hp). In 2004, a new 9½-in. downhole motor was developed that delivers 975 rev/min at 1,055 gal/min (1,025 hp).

Weight on Bit (WOB). In 2004, the maximum WOB for high-speed downhole motors was approximately 48,100 lbm. With the 975-rev/min downhole motor, maximum WOB increased to 60,700 lbm because of improvements in bearings.

Flow Rate. In northwest Germany, salt sections occur at relatively deep depths above the Bunter. The mud weight required to drill the salt varies from 13.3 to 15 lbm/gal. With 5-in. drillpipe, flow rates with this mud weight are limited to 600 to 660 gal/min. Because of this high mud weight and low flow rates, turbines could not be used effectively because of the high differential working pressure. Downhole motors were preferred.

Today, use of 6-in. drillpipe allows operation of the 975-rev/min downhole motor up to the operational limits of these motors. Even at 13.3- to 15-lbm/gal mud weights, the 5,000-psi rig pumping-pressure limit is sufficient.

DOC. Impregnated-bit DOC depends on rotary speed, WOB, and flow rate. Flow rate has a direct influence on bottomhole cleaning, which affects ROP. The influence and relationship of these parameters must be derived from actual drilling data and drilloff tests.

Data at different bit rotary speeds were collected for 400-, 780-, and 975-rev/min-motor applications. Plotting these data at a constant WOB shows DOC decreasing with increasing

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For a limited time, the full-length paper is available free to SPE members at www.spe.org/jpt. The paper has not been peer reviewed.

rotary speed. DOC is directly related to WOB and increases with increasing WOB. The DOC for a given WOB is greater at higher flow rates.

Overbalance

The effect of overbalance on drilling is well known in the drilling industry. Drilloff-test data show that the influence of flow rate is larger in very-high-overbalance situations. Wells that did not achieve noticeable DOC at flow rates less than 660 gal/min had high differential pressures at bottom. This leads to the conclusion that a bottomhole bit-balling effect occurs at high overbalance. A bed of fine cuttings and mud components hinders the diamond/formation contact at insufficient flow rates. An increase in flow rate leads to cleaning of this debris, resulting in a greater DOC.

New Downhole Motor

Drilloff-test results show an almost linear relationship between DOC and flow rate. A new downhole motor was developed and built in 2004 to increase DOC by increasing flow rates. This new downhole motor uses a new stator technology. Instead of a conventional stator, the stator is precontoured in the steel of the stator pipe and covered by a thin layer of polymer. Because of improved bearings, higher WOB can be used and motor durability is improved.

Bits and Stabilizers

New materials and manufacturing processes made it possible to build third-generation impregnated bits. A typical impregnated bit used to drill the Bunter formation in the late 1990s had a continuous cutting structure **(Fig. 1).** Typically, these bits were worn down after less than 500 ft in the Bunter. The diamond quantity was increased to make the bits more durable. A third-generation 12¼-in. impregnated bit has almost four times the diamond quantity of a first-generation impregnated bit. Improved cooling of the impregnated-bit segments in the new-generation bit was accomplished by an interrupted cutting structure and optimized fluid courses (Fig. 1). Bits with a long gauge now are used with high-speed motors to prevent a spiral hole and to replace the near-bit stabilizer that wore down very quickly at high rotary speeds, especially in deviated holes.

Stabilizer wear also is an issue for wellbore and well-path quality. Some of the conventional stabilizers protected by tungsten carbide showed total wear after a 140-hour run in the Bunter formation. A new stabilizer design with diamond protection was tested in four runs in three Bunter sections for a total length of 2,960 ft and 240 hours. The new stabilizer design shows a significant reduction in wear and contributes to a better-quality wellbore.

Field Data

During the last 3 years, data from six wells drilled through the Bunter section with 780- and 975-rev/min downhole motors and impregnated bits were collected and analyzed.

Well A. In 2003, a combination of new-design 12¼-in. bit, 9½-in. 780-rev/min motor, and 6⅝-in. drillpipe was run for the first time. Total footage drilled was 2,507 ft and the inclination was increased from 36 to 48°. At the first roundtrip after drilling 1,093 ft of the Middle Bunter, the remaining cutting structure height of the original 1.0 in. was 0.4 in. The remaining 1,414 ft of the section was drilled with a new bit. When pulled out of the hole, the second bit had a remaining cutting-structure height of 0.7 in. Overbalance in this well was 1,650 psi.

Well B. Well B, drilled in 2004, was the fifth well in a field. The same type of BHA was used as in Well A, including the impregnated bit from the second bit run of Well A. The mud weight was nearly at balance with the pore pressure in the Bunter. For the first time in this field, the 1,920 ft Bunter section was drilled in one run with a 12¼-in. BHA. Average ROP was 14.7 ft/hr, which is twice the speed attained in the preceding wells in this field.

This bit drilled a total of 3,333 ft in two runs and set a world record for 12¼-in. impregnated bits. After approximately 15 million revolutions at more than 750 rev/min in deviated wells, the bit was still in gauge.

Well C. In Well C, drilled in 2004, two different high-speed downhole motors were used. Mud weight was nearly at balance with the pore pressure in the Bunter. ROP in previous wells in this field in the 1990s was approximately 3 ft/hr in 8½-in. holes and less in 12¼-in. holes. Average ROP in this well was 8.8 ft/hr, and maximum ROP was nearly 10 ft/hr. The main differences between the motors were transmission and limitations in flow rate.

Data from drilloff tests of both motors at different flow rates were plotted. The curves indicate potential for DOC improvement at lower rotary speeds and at significantly lower flow rates. However, a minimum flow rate for sufficient bit cooling and hole cleaning must be guaranteed.

Well D. In 2004, a prototype of the 975-rev/min downhole motor was used for the first time in Well D. At a 1,055-gal/min maximum flow rate and 60- to 100-rev/min string rotary speed, the bit was rotating at more than 1,000 rev/min. A 19-ft/hr maximum ROP was achieved at maximum flow rate and a WOB that was limited operationally to 50% of nominal. This ROP is a 20% increase from Well A at the same WOB and a lower flow rate of 845 gal/min. Average ROP was 12.9 ft/hr.

Well E. In 2005, Well E was drilled in close proximity to the field of Well C. Average ROP on this well was 10.1 ft/hr. In this well, the new diamond-protected stabilizer was run for the first time, and it was the second application of the 975-rev/min motor. At a high WOB, the bit wear in the upper part of the Middle Bunter formation was much higher than expected. It was found that, in these extremely hard and abrasive formations, high temperatures were generated at the bit and even 1,000-gal/min flow rates were not sufficient for bit cooling. The diamond-protected stabilizer was still in good shape and was run in Well F after finishing the Bunter section on this well.

Well F. Well F was drilled in 2005 in the same region as Well D. The average ROP on this well was 13.1 ft/hr. The BHA in this well was similar to the one used in Well E, with the 975-rev/min motor and the diamond-protected stabilizer. The impregnated bit on this well was from a different manufacturer but had a similar quantity of diamonds. Bit specifications and bit-wear experiences in Well E were reasons for initial WOB limitations. The entire 1,517-ft section was drilled with one bit that showed 50% wear and was still in gauge when pulled out of the hole. The diamond-protected stabilizer was good for another run in the next Bunter section. JPT