First TTRD Well Drilled From a Floating Platform—Concept Study to Reality

The full-length paper describes the concept study, preplanning, and drilling of the world's first through-tubing rotary (TTR) -drilled well drilled from a floating platform. The full-length paper details the challenges of maintaining the integrity of the existing subsea well completion together with the specific bottomhole-assembly (BHA) requirements to drill in this highly depleted reservoir.

Introduction

The Hydro-operated Njord field is approximately 130 km northwest of Kristiansund and 30 km west of the Draugen field in 350 m of water in the North Sea, and is being developed from a floating steel platform (Njord A). Production began in 1997, but the field already is mature with a rapidly declining oil production. Oil production currently is approximately 35,000 B/D from eight oil producers; associated gas is injected into four gas injectors. Infill drilling is the most important (promising) measure to increase oil recovery. The reservoir is very complex with numerous faults and unconnected reservoir segments.

In May 2005, Well 6407/7-A-9 AH was drilled as a test well and technical-qualification well for a possible TTR-drilling (TTRD) campaign in Njord. Well A-9 AH proved that the concept of sidetracking from existing wells without retrieving the existing completion and horizontal Christmas tree was feasible from a floating platform with conventional rig equipment.

*This article, written by Assistant Technology Editor Karen Bybee, contains highlights of paper SPE 98880, "World's First TTRD Well Drilled From a Floating Platform in the Njord Field, North Sea—From Concept Study to Reality," by **T. Flatekvaal,** SPE, Hydro E&P; **E. Saeverhagen,** SPE, **O.E. Eng,** SPE, and **N. Jepson,** SPE, Baker Hughes Inteq; **J. Oyovwevotu,** SPE, Leading Edge Advantage; and **J.F. Namtvedt,** SPE, and **M.M. Price,** SPE, Hughes Christensen, prepared for the 2006 IADC/SPE Drilling Conference, Miami, Florida, 21–23 February.*

Fig. 1—Bicenter bit.

Feasibility Study

The Njord petroleum technology department established a task force to evaluate all wells for possible sidetrack candidates. Evaluation showed that drilling ordinary sidetrack wells would not be economical because abandonment of existing producing wells would leave behind unproduced reserves, and the cost of retrieving the existing completion string including the horizontal Christmas tree would be too high to be cost-effective because of the marginal additional reserves in each new target.

Compared to TTRD operations from fixed platforms, the following technical challenges had to be resolved to drill subsea TTRD wells from the floating Njord platform

- Damage to the existing completion string, including the horizontal Christmas tree, the seal areas for the tubing-hanger barrier plug, and the internal tree cap.
- The influence of rig dynamics, including heave, pitch, and roll on wear on the existing well completion.
- Damage to the tubing downhole safety valve (DHSV) at 850 m.
- Effect of rig heave on swab and surge in wells with small inside-diameter (ID)/outside-diameter tolerances and on depletion-induced weak formations.
- Required annular velocity in the marine riser to avoid critical accumulation of cuttings in the 19-in.-ID marine riser and subsea blowout preventer (BOP).
- Mud rheology effects resulting from mud cooling in the 360-m marine riser.
- Well-control issues because it was impractical to trip into the well through the subsea-BOP annular preventer.
- Increased focus on early kick detection because of the marginal well volume underneath the subsea-BOP stack.

Because of these critical issues as well as a number of nonproven new technologies, a project group was established reporting weekly to the project steering committee. Special attention was paid to qualification of the directional-drilling BHA. Evaluations of alternative concepts were necessary to meet the requirements for the following.

- Low string RPM combined with continuous string rotation.
- High dogleg capability.
- Real-time measurements of drilling and formation-evaluation-logging data.
- The ability to drill a larger hole than permitted by the restrictions of the existing well completions.

These key criteria were met by introduction of new drilling technology as well

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as modifications to existing technology. The conceptual BHA design had to be field proved before drilling Njord.

Team Effort

Because geometrical requirements to reach the geological targets for the TTR-drilled wells planned for the Njord field exceeded the capabilities of most current rotary-steerable systems (RSSs), Hydro selected one vendor to enter into a study to develop the current TTRD BHA to drill through the Njord well restrictions with the required geometrical build rates.

The team of engineers and consultants from the operator and engineers, designers, and operations personnel from the service companies began the process of addressing TTRD and directional challenges by setting objectives and defining the work scope for the different project phases.

The overall objective of the team was to develop an economical solution to drill an extended-reach lateral section with as large a diameter as possible, while passing through a DHSV with a 5.84-in. pass-through ID. The well profile required a 6-to-8°/30-m dogleg severity (DLS) to hit the directional target, while minimizing wear on tubing and the DHSV.

Work Scope

The team agreed on the drilling challenges and target performance. This included data collection, offset studies, benchmarking, and an evaluation of commercially available drilling technology. The team identified two key technologies as critical to solving the drilling challenges.

- A new, extremely high-power modular motor to complement the RSS.
- A novel bit design to expand the wellbore, while minimizing drilling dynamics.

Conceptual designs of both the modular motor and drill bit were tested through application-based laboratory simulation and full-scale drilling-rig testing. Proprietary computer modeling was used to analyze bending moments and verify achievable DLS. Design and application modifications were reworked on the basis of testing results. The proposed solution then was implemented and used in a commercial well.

TTRD Concept Engineering

BHA Design. To design a BHA for this application, it was crucial to obtain a thorough overview of the conditions and restrictions in the Njord field. There were challenges to maintain the integrity of the existing subsea well completion by not damaging the 5⁷/₈-in. DHSV and the 7-in. production tubing, and drill in and out of highly depleted reservoirs (from 430 to 150 bar) with low formation strength, numerous unknown faults, and a history of severe mud losses and stuck pipe in a previous drilling campaign. Several different BHA design studies were performed, each one risk assessed to determine the optimum design for this application.

RSS. The $4^3/_4$-in. RSS existed as a pilot test series for a flow range from 611 to 1325 L/min. There was a requirement to design and manufacture a low-flow system with a 475- to 700-L/min flow range. This ruggedly built, modular-design drilling and evaluation tool is available for hole sizes between $5^7/_8$ and $6^3/_4$ in. and consists of an automatically controlled steering unit that can steer itself during continuous rotation, modular stabilizers, a formation-evaluation subassembly, and a separate subassembly that provides bidirectional communications for two-way communication between surface and downhole. All these components had undergone extensive flow-loop and casing-drilling tests.

Modular Motor. A modular $4^3/_4$-in. positive-displacement-motor (PDM) section integrated in the $4^3/_4$-in. steerable BHA had to be designed and manufactured. The $4^3/_4$-in. modular motor is based on a proven extremely high-power PDM design that incorporates a hard-wired communications bus to transmit measurement-while-drilling (MWD) power and data. This allowed integration of the high-power PDM motor below the logging-while-drilling (LWD) suite but above the $4^3/_4$-in. RSS steering unit, reducing rotary-speed strain on the MWD/LWD electronics.

PDM as Backup Solution. As a contingency solution, an extremely high-power $4^3/_4$-in. PDM with a 6-to-10°/30-m DLS capacity was required to be available for drilling and as a backup drive for milling the casing-exit window. The high-power motor has a steel rotor and stator. The steel stator is covered with a thin rubber layer that makes this motor unique among PDM motors. The design enables maximum power to the bit with very little chance of stalling. With a steel rotor and stator, increased strain on the motor is seen as an increase in standpipe pressure, while the speed is affected only slightly. The motor does not allow a stall-out in normal terms, because the standpipe pressure will actuate the "pop-off" valves before a theoretical stall point is reached. This increased power and torque level is essential when driving milling BHAs.

Bicenter Bit. A bicenter-bit design was introduced to drill a large wellbore in the lateral section. The bicenter bit is a one-piece tool designed to drill and enlarge the hole in one trip without moving parts. The three main geometric characteristics of bicenter bits are the pass-through diameter, which is the smallest hole size the tool can pass through when tripping; the pilot-hole diameter, which is the size of the pilot portion of the bit; and the drill size, which is the size of the hole the tool drills when rotated.

Bicenter-Bit Design. After a thorough analysis of commercially available bit technology, the team determined that the bit should incorporate the following bit technology.

- State-of-the-art abrasion-resistant cutters to maximize bit durability and run longevity.
- Depth-of-cut-control technology to minimize bit vibration and stick/slip with the RSS.
- Eccentric cutting structure to pass through the $5^7/_8$-in.-ID DHSV and drill a larger wellbore.
- Proprietary gauge features to maximize bit durability while allowing sufficient side-cutting ability to achieve as much as 10°/30-m DLS.

Fig. 1 shows the final bicenter bit design.

Test Well

The decision was made during the preplanning stage that all equipment used on Njord should as far as possible be field proved. Because of this, it was necessary to qualify the functionality of the complete $4^3/_4$-in. BHA system in a configuration as close as possible to the configuration that would be deployed on the Njord TTRD project, with hole-angle conditions approaching those planned for the Njord TTRD campaign. An experimental test area close to Tulsa was used to drill a directional well that simulated hole conditions comparable to the proposed deployment in the Njord field in Norway.

Downhole BHA components as well as the surface system were tested for BHA performance. In addition to the $4^3/_4$-in.

RSS, the new bit also was part of the test. The bit had to create a hole sufficiently large and of the required quality for the RSS to be able to function in terms of the test qualification criteria.

The concept was proved to function according to design in the test well and was ready for drilling from a floating installation into a real reservoir.

Njord Well 6407/7-A-9 AH

TTRD BHA Design. Because all of the BHA equipment had tested successfully, no major changes were made to the TTRD BHA design. The following components were altered from the test-well equipment.

- The high-flow turbines were changed to low-flow turbines in the power module and in the RSS because of reduction in flow from the test site to offshore on Njord A.
- The modular motors were changed from a high-speed to a low-speed version to reduce possible wear in the RSS.

Well Design. The well path was planned to be drilled from 4470 to 5697 m measured depth with a maximum 5.8° DLS, starting at 66° inclination and drilling up to 116° inclination. Hole size was 5.921 in. (5.8-in. pass through). Weight on bit was 2.5 to 7.5 tons. Surface, motor, and bit speeds were 40, 59 to 89, and 99 to 129 RPM, respectively. Flow rate was 475 to 708 L/min. An oil-based mud system designed for high-pressure/high-temperature application was selected.

Run Summary/Statistics. Two mill runs were required to mill out the window in the tubing. The first attempt was unsuccessful because the standard PDM stalled out soon after milling began. The contingency plan called for use of an extremely powerful PDM, which enabled problem-free milling of the window. A 4-m tubing window and 10 m of rathole were milled/drilled.

The well was drilled in two runs. The first run drilled 23 m before pulling out of the hole because of poor DLS capability. The second run drilled to total depth (TD) at 4726 m, meeting the required criteria for the well.

Results. The following summarize the results of drilling the actual well.

- The modified low-DLS casing-exit system showed good performance.
- Two mill runs were required to mill out the window in the tubing. The first attempt was unsuccessful because the standard PDM stalled out soon after milling started. The contingency plan called for use of an extremely powerful PDM, which enabled problem-free milling of the window.
- The well was drilled without damaging the horizontal subsea Christmas tree or DHSV. The protection sleeve installed by piggyback subassembly was adequate for these operations.
- The drilling BHA with a combination of bicenter bit, RSS, and modular motor performed according to specifications for the directional Njord TTRD wells.
- Existing-completion tubing wear after 235 000 pipe revolutions was less than predicted and in the range of 0 to 4%, determined by logging the wall thickness before and after drilling operations. JPT