Rotary steerables optimize Troll field production

Klaus-Dieter Ernesti, Baker Hughes INTEQ

ECONOMIC DEMANDS HAVE long been the driving force behind innovations in drilling and formation evaluation technology within the oil and gas industry. Still, operators and service providers have had to work together to develop equally innovative applications in order to gain maximum value from these technology advancements in complex reservoirs such as those found in offshore Norway's Troll field.

The development of closed-loop drilling systems, detailed, real-time drilling dynamics and comprehensive logging while drilling (LWD) has been critical in the step changes required to meet Troll development goals.

Likewise, detailed analysis of the technology's application with a focus on the Troll field's unique drilling challenges have led to the design of specific bottom hole assemblies and drilling practices, optimizing drilling efficiency and wellbore placement to facilitate the development of previously uneconomic reserves.

APPLICATION CHALLENGES

The Troll field is operated by Hydro and located on the Norwegian Continental Shelf some 80 km west of Bergen in the North Sea. From a drilling and evaluation perspective, the Troll field's main challenges can be divided into three main categories.

First, the thin oil column (between 8-27 m depending upon field location), requires effective true vertical depth (TVD) control throughout the entire horizontal section in order to place the well near the oil/water contact (OWC) for optimal recovery.

In addition, there is also a gas field on Troll with an even thinner oil column (approximately 4 m) that is currently not economically viable despite today's advanced technology.

Secondly, the dramatic differences in formation drillability throughout the reservoir present significant challenges in regard to drill bit durability and directional control (specifically TVD control).

The Troll field's mica-rich and coarse reservoir sandstones possess an unconfined compressive strength (UCS) of 3,000 to 6,000 psi.

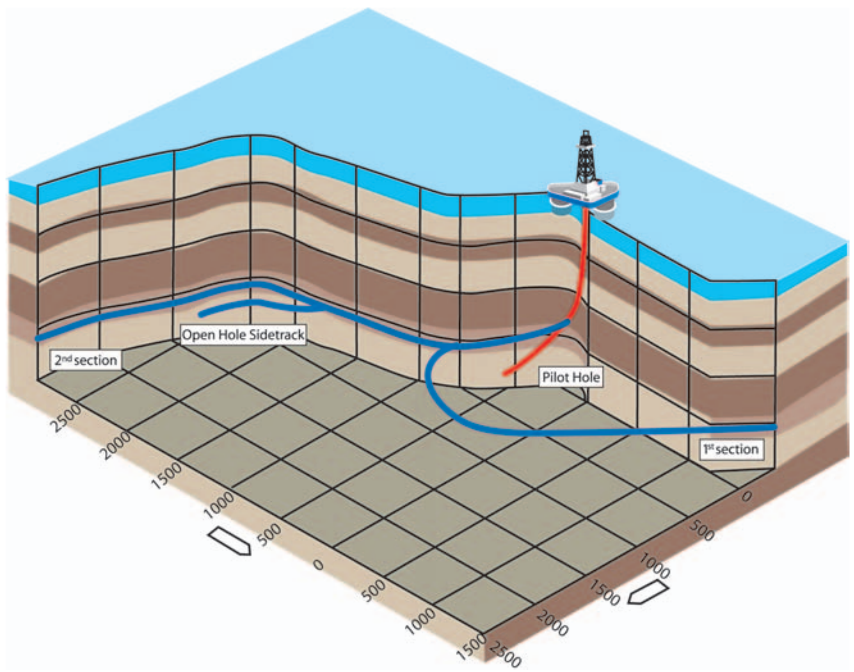
These formations are generally drilled with relative ease but penetration rates are often limited to 60-80 m/hr in order to provide an optimal equivalent circulating density (ECD) and ensure real-time data log density.

However, the field's sandstones also possess calcite-cemented stringers that take the form of thin layers, nodules or lenses in the reservoir, creating high variations in drillability and UCS (up to 25,000 psi). The achievable penetration rate in the more densely cemented stringers can be less than 1 m/hr.

Finally, the complexity of the long horizontal sections coupled with the demanding well profiles required to stay within the desired sands present a substantial challenge for drilling system equipment.

In addition, all of these wells are multilateral designs with up to four reservoir branches (including open hole sidetracks) being drilled from one mother bore.

This increases both well design and execution complexity. It is not uncommon for these multilaterals to require over 14,000 m of reservoir section to be accurately drilled and positioned in order to achieve maximum recovery.



Troll field challenges facing the operator included a thin oil column, dramatic differences in formation drillability throughout the reservoir affecting directional control, and complex long horizontal sections coupled with demanding well profiles.

ROTARY CLOSED LOOP SYSTEM

The biggest step change in drilling efficiency and TVD control on the Troll field was achieved in 1998 with the introduction of Baker Hughes INTEQ's AutoTrak® Rotary Closed Loop System (RCLS).

The system's closed-loop control, optimized sensor spacing includes near bit inclination (NBI) measurements located 1 m behind the bit and gamma and resistivity LWD sensors 6 m behind the bit.

They were applied in combination with the system's enhanced weight transfer to extend the achievable section length by 1,000 m versus previous drilling systems.

In 2002, drilling efficiency and wellbore placement accuracy on Troll was further enhanced with the introduction of a next-generation RCLS.

In addition to minimized sensor-to-bit spacing, the new system was designed with modular components to simplify handling on the drill floor and permit greater flexibility in the bottom hole assembly (BHA) configuration to best match the needs of specific applications.

BHA CONFIGURATION

On Troll, this has permitted the application of three distinct BHA configurations. The standard BHA for reservoir drilling benefits from the system's inherent stiffness to improve directional control in calcite-enriched formations for optimum well placement and reduced wellbore tortuosity. Field experience has shown the stiffer drilling system is less influenced by formation changes and the resulting changes in formation drillability.

More than 100 PDC bit design iterations were used on the Troll field, leading to improved cutter design and geometry as well as enhanced bit hydraulics and gauge configuration. The current standard bit features 19 mm cutters, seven blades and a 6-in. long gauge.

A second, more flexible BHA configuration was employed for rotating over a whipstock and drilling the first 70 to 100 m. This assembly is designed to reduce the bending moment exposure of individual string components while drilling through the high dogleg severity of the whipstock area.

In 2004, a third BHA configuration was introduced that combined rotary steerable systems with advanced positive displacement motor (PDM) technology. The AutoTrak X-treme® system merged the directional capabilities of the closed loop rotary steerable and increased power of an advanced PDM. The modular motor is integrated in the system and placed directly above the steering unit.

This BHA configuration is designed to reduce the amount of string revolutions, minimizing wear on the drillstring components and casing. In addition, decreasing string rotation serves to reduce vibration severities and increase overall system reliability.

Results from Troll demonstrate that the field's various reservoir formation types can be drilled with bit rotation in excess of 250 RPM and penetration rates comparable to the standard BHA configuration but with a 50% reduction in the string rotation.

In addition, the RCLS/PDM combination system enables sliding operations in the event of high unwanted localized doglegs, minimizing load exposure to the string components.

REAL-TIME LOGGING

The various BHA's can be further modified with multiple LWD subs to match the application's formation evaluation requirements and best take advantage of the system's directional control and reservoir navigation capabilities.

Azimuthal gamma and azimuthal density measurements are used frequently in the Troll field to identify formation layers and dip orientation in order to geosteer within the desired sands.

A TesTrak™ LWD sub was used successfully to gather formation pressure and mobility data during drilling operations to permit geological and connectivity models to be updated in real-time to facilitate optimal wellbore placement.

The drilling process is temporarily interrupted, pressure and mobility is measured and the results are transmitted to the surface.

There is no need to halt normal circulation and accurate tests can be completed in as little as 10 minutes. As a result, traditional wireline operations are often eliminated, reducing NPT and further improving project economics.

Another key efficiency driver in the Troll field was the addition of advanced, real-time CoPilot® Drilling Dynamics®. The service comprises an advanced downhole dynamics tool that measures numerous downhole parameters including lateral and axial vibrations, stick-slip, downhole bending moment, weight-on-bit and torque, whirl, torque shocks, pressure and temperature measurements with a sampling frequency of 1,000 Hz. Due to the wealth of data sampled, a processor board is incorporated in the downhole tool to calculate the diagnostics and severity levels.

After processing all data downhole, diagnostics and severity levels are transmitted to surface via the standard MWD pulse telemetry and the raw data are recorded in the tool's memory for further detailed analysis.

At the surface, a specially trained rigsite engineer proactively analyzes the data to ensure the drilling parameters employed provide the most efficient energy transfer to the bit, mitigating harmful drilling dysfunctions and minimizing detrimental BHA loads.

Maintaining optimum parameter setting also prolongs bit life by reducing the potential for impact damage and premature wear. Positioning the drilling dynamics sub close to the bit reduces the risk of unwanted directional deflection when drilling calcite-enriched interbedded formations and allows the driller to use the bending moment data proactively when turning the well azimuthally in the horizontal plane.

DRILL BIT DEVELOPMENT

While an integrated BHA design played a key role in improving drilling efficiency, innovative drill bit designs were also critical in addressing the Troll reservoir's drillability challenges (i.e., soft sands and hard calcite cemented stringers). These bit designs incorporated both PDC and roller cone drill bit technology.

On current Troll applications, the drill bit selection and strategy is based on a thorough understanding of the drilling environment and the drilling program requirements. This, together with the latest developments in PDC and roller cone drill bit designs from Hughes Christensen led to significant performance improvements.

To date, over 100 PDC bit design iterations from **Hughes Christensen** have been used on Troll. This excessive testing has led to improved cutter design and geometry as well as enhanced bit hydraulics and gauge configuration, significantly increasing both drill bit stability and durability.

The current standard PDC drill bit for

Troll features 19 mm cutters, seven blades and a 6-in. long gauge.

PRE-WELL PLANNING

Pre-planning and the application of best practices ascertained during drilling have been instrumental in bit selection in the Troll field and the resulting performance improvements.

The pre-well planning includes a comprehensive review of geological data from the well program and a thorough study of offset wells and their lithology data to provide comparable stratigraphic characteristics being summarized in a section prognosis.

The entire drilling and evaluation system is configured to best match the specific application challenges to ensure that the desired drilling practices and performance are not compromised by inappropriate drill bit or BHA selection.

While drilling, the drilling plan is reviewed against real-time well data and, if necessary, the section strategy is adjusted to provide optimal drilling efficiency.

Hughes Christensen, in cooperation with INTEQ, has developed a formation evaluation program for enhanced data analysis and drill bit recommendations during drilling.

This program is based on experience gained while drilling more than 394,000 m (1.3 million ft) of Troll reservoir.

The program compares selected FE parameters to determine formation drillablity and UCS and has already led to a change in overall drill bit strategy.

Today, roller cone drill bits are only used in the Troll field for planned short runs or when dictated by formation properties. Based on this increased knowledge of the drilling environment, the relationship between reservoir meters drilled on Troll with PDC bits and that drilled with roller cone bits has changed from 36:64 in 2002 to 92:8 by the end of 2004.

The ultimate goal is to drill all reservoir sections with PDC drill bits alone. These developments were made possible through a "system" approach to drilling challenges and required dedicated support and commitment from not only the drilling services and bit provider, but also the operator.

TOTAL SYSTEM APPROACH

Since 1998, several improvement initiatives have been undertaken in order to increase overall performance on Troll and better address the field's specific application challenges.

Hydro has worked closely with Baker Hughes, drill bit suppliers and, most recently, rig contractors in order to develop and implement these improvements.

A "total systems approach" was always considered a critical component and the results from these initiatives clearly demonstrate an increase in overall performance and efficiency on Troll.

As part of a systems approach to drilling, it is vital that involved personnel focus on all the various aspects of the application and that they are constantly updated as to any changes to the well objectives over the entire "life cycle" of the drilling program (planning, execution and review).

In addition to regularly scheduled operator-based morning meetings, numerous meetings are conducted between INTEQ's onshore operation center and the operation office. These meetings typically include the project leader, and optimization, bit and drilling engineers. Topics range from detailed reviews of drilling progress to the next day's anticipated challenges.

Relevant historical and engineering data are captured and communicated to the offshore crew.

Lessons learned from each deployment are used to proactively enhance the system selection (BHA and drill bit) process, further increasing efficiency on upcoming wells.

The implementation of this total systems approach led to significant increases in drilling performance including a 54% ROP increase and extending run length (footage per BHA) by 92% over a single, twelve-month period.

CONCLUSION

The thorough analysis and optimization of BHA and drill bit selection, application of specific drilling procedures, enhanced planning methods, increased understanding and awareness of the downhole drilling environment and close cooperation between all involved parties were the critical factors in the Troll field's overall performance improvements.

It has been estimated that more than $6 billion of incremental production revenue had been achieved through the application of the aforementioned drilling and evaluation technologies and the implementation of this total system approach. ■