

Continuous Circulation System debuts with commercial successes offshore Egypt, Norway

By Rod Vogel, National Oilwell Varco

IN 2005, THE National Oilwell Varco Continuous Circulation System (CCS) successfully completed its first commercial application offshore Egypt. This new and enabling technology was used to re-enter the Port Fouad Marine Deep 1 well and drill previously undrillable 8 1/2-in. and 5 7/8-in. hole sections through a prospective reservoir below 4,500 m. In March 2006, a second unit was used to drill an 8 1/2-in. section of deviated hole from below 5,000 m in the Kristen field offshore Norway.

THE CCS

The system was developed as the result of a UK Joint Industry Project started in 2000 and supported by 6 major international oil companies, with design and engineering from **Varco-Shaffer** (now National Oilwell Varco). The CCS allows drill pipe to be added to or removed from the drill string when drilling or tripping without interrupting circulation to the well bore. It can be installed on any medium/large rig equipped with a top drive.

The system works by enclosing the connection in a pressure vessel, basically a triple BOP body with upper and lower (inverted) pipe rams and central blind rams. The cavity is pressurized with mud from the standpipe and the pin connection backed out and raised clear of the blind rams, which are then closed. Circulation through the top drive is stopped and the upper chamber depressurized, while circulation continues uninterrupted into the open box below the blind rams. A new drill pipe stand or single is picked up by the top drive and stabbed into the upper chamber. The pipe rams are then closed and the chamber filled before opening the blind rams and lowering and making up the connection while restarting circulation through the top drive. The chamber is then depressurized and the pipe rams opened, allowing drilling to continue.

NOV'S CCS MAIN UNIT

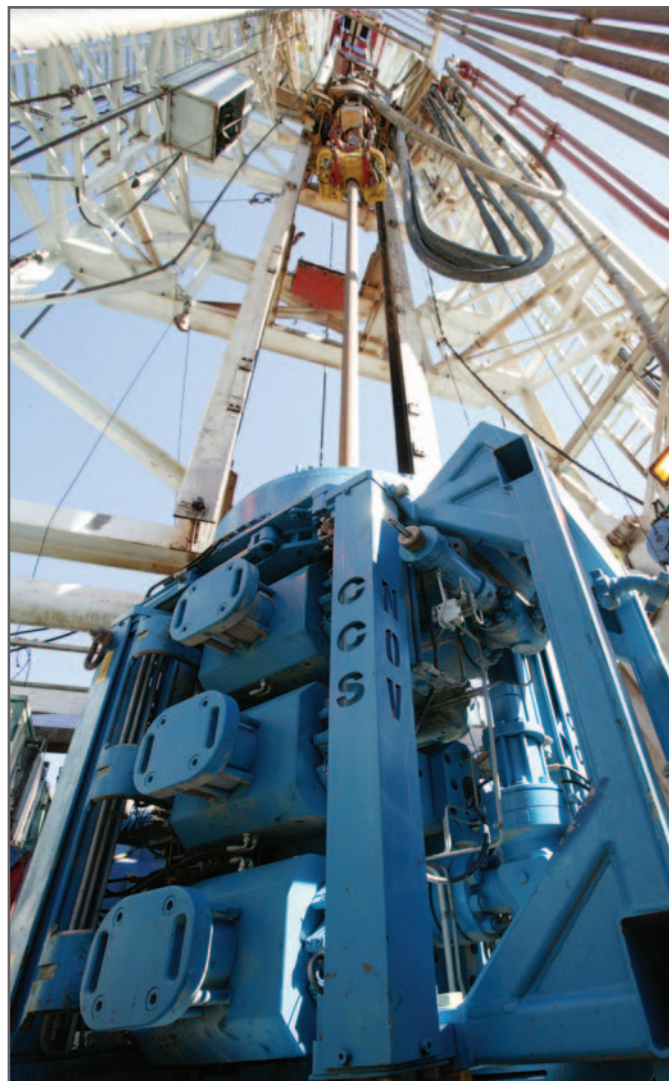
The prototype CCS was successfully tested in July/August 2003 on a small land rig drilling for BP in Oklahoma. Seventy-two connections were made with 4 1/2-in. IF drill pipe while circulating at 800 gpm between 2,800 and 3,000 psi.

DEVELOPMENT

Following the trial, the system was redesigned, principally to reduce the size and weight of the main unit and to upgrade the control system to permit the CCS to be safely operated by trained personnel in an operating drilling rig environment. Design and testing of the additional components that make up the system was also completed.

The CCS components are:

- **Main unit**, located on the rig floor over the rotary table.
- **Mud diverter unit**, which controls the mud flow between the top drive and the main unit.
- **Extension/wear sub**, connected to the top drive and positions the connection inside the main unit.



The main unit on the Continuous Circulation System is located on the rig floor over the rotary table. The CCS allows drill pipe to be added to or removed from the drill string when drilling or tripping without interrupting circulation to the well bore.

- **Top drive connection tool**, used to handle stands in the derrick and connect/disconnect the extension/wear sub to/from the top of the stand in the derrick; comprises a hydraulic tong and dual-sided elevators.
- **Touch screen controls (HMI)**, located on rig floor.
- **Hydraulic power unit**, located in a custom container that also provides hose and cable storage in transit and houses data recording/storage "black box" with Internet communication to NOV's 24/7 Houston Engineering Support Center.

RECORDING AND REPORTING

From the onset, NOV realized that the successful introduction of the CCS depended on gaining the confidence of drilling engineers and operations personnel in the reliability and safety of

the system. For them to program the use of a new and relatively unproven system to drill difficult and costly wells, they must be confident that it will deliver the performance and reliability required. For this purpose, a CCS performance data gathering and reporting system was developed, available to both NOV and operators' drilling personnel. The system comprises:

- Daily drilling report: containing details of drilling activities during the day, particularly those involving the CCS; also lists pertinent well engineering data, including hole size and depth, bit type, BHA configuration, mud weight, circulating rate and pressure, ECD measurements and casing information.
- CCS connection data summary: a detailed record and analysis of every connection made with the CCS.
- CCS issues log: a record of any incidents that occur during a connection or issues to be resolved, who is responsible for following them up and the outcome.
- Consumable usage log: includes a record of usage CCS Ram Rubber Assembly (RRA) and other consumable usage and performance.
- CCS maintenance log: a record of maintenance carried out on the system and by whom.

From the data summary, graphical presentations can be prepared of time taken for each stage of each connection and of standpipe pressure and lower chamber pressure at each stage.

The daily report is submitted to both the operator and the local NOV base manager. Experience has shown that a philosophy of totally transparent reporting to all stakeholders adds additional motivation for personnel to achieve exceptional operating performance. Separate internal reports within NOV are neither made nor permitted. This enables clients to deploy the system with the confidence that their drilling objectives can be achieved, safely and effectively.

Connection via the Internet is 24/7 to the NOV Houston Engineering Support Center during operations with the stated aim for the CCS of achieving and maintaining "jet engine reliability." The system continuously monitors the performance of the CCS components and allows expert staff members located at the support center and at their homes to be consulted day or night on equipment problems or malfunctions. If necessary, adjustments to component operating parameters can be made remotely via the Internet connection. This system has contributed to remarkable performance with only one downtime incident on the first application (less than 3 minutes) and 100% performance during operations on the first project in Norway.

APPLICATIONS

The ability to drill long sections of hole without stopping circulation while making connections has a range of potential applications. Of these, the most significant is the ability to drill through formations where the gap between pore pressure and fracture pressure gradients is very narrow. Each time circulation is stopped to make a connection and then restarted, the pressure fluctuations experienced by the well bore leads to mud losses and flows and subsequent well bore instability. With continuous circulation, a stable, balanced pressure condition can be established and drilling can proceed using the dynamic circulating pressure or equivalent circulating density (ECD) to control the well.

This principle was used in the first 2 wells.

The well was drilled in 2004 and had previously been suspended with 9 $\frac{5}{8}$ -in. casing set at 4,244 m above an extensive and potential high-pressure gas reservoir. Severe drilling problems had been encountered when drilling 8 $\frac{1}{2}$ -in. hole. As the window between the pore pressure and fracture pressure gradients narrowed, drilling conventionally led to a series of problems. Formation ballooning, gas flows on connections, gas kicks, loss of circulation and generally unstable well bore conditions resulted in many days of nonproductive time (NPT) and the inability to drill to the target depth to evaluate the extent of the reservoir. The well was suspended as a gas discovery but with the full extent of the reservoir undetermined.

As a result of their company's association with the JIP to develop the CCS, Eni drilling personnel were familiar with the system and believed that using it, the well could be re-entered and the reservoir safely and successfully drilled. Maintaining uninterrupted circulation during connections would allow the balanced pressure drilling technique to be used. The formation pore pressure and ECD could be continuously measured and evaluated with MWD/PWD tools, allowing the circulation rate to be controlled to keep the ECD within the critical gradient zone (CGZ), the narrow band between the pore pressure and fracture pressure gradients. The potential for gas kicks and mud losses would be minimized, allowing the extent of the reservoir to be determined and valuable data recorded. This benefit would more than justify the rental cost of the system plus the cost of rig time involved in rig up/down.

Ahead of the PFMD 1 re-entry operation, Eni tested the system on a land well in the Vald'Agri field in southern Italy, where 660 m of 12 $\frac{1}{4}$ -in. hole were drilled and 82 connections made while circulating continuously at 600 to 750 gal/min and 2,000 to 3,000 psi and building angle from vertical to an inclination of 35°.

The CCS was then mobilized to Egypt and installed on the Maersk Endurer jackup rig drilling for Eni/Petrobel in the Port Fouad Marine complex in the Mediterranean. The re-entry program for PFMD 1 involved cleaning out the suspension plugs to below the 9 $\frac{5}{8}$ -in. casing shoe, rigging up the CCS and cleaning out the previously drilled 8 $\frac{1}{2}$ -in. hole with uninterrupted circulation while



This map shows the location offshore Egypt where the Continuous Circulation System successfully completed its first commercial application in 2005.

adjusting the mud weight and circulation rate to give an ECD value in the CGZ between the pore and fracture pressure gradients. Typically this required an ECD of 2.06-2.07 SG achieved with 1.99 SG mud circulating at 380-400 gpm. The 8 $\frac{1}{2}$ -in. hole was successfully deepened by 402 m before a major gas kick and losses were encountered and a 7-in. liner run. During this period, no hole problems were encountered, the drill string had been tripped and wireline logging tools successfully run. Drilling the 5 $\frac{7}{8}$ -in. hole required a rotating BOP and associated annulus control equipment and the adoption of closed-hole drilling procedures in addition to the CCS.

The well was deepened by a further 253 m while bullheading 2.0-2.2 SG mud to the drill pipe and bleeding off gas from the annulus at 500-800 psi. MWD/LWD logs and surveys were recorded, and with uninterrupted circulation while making connections, the hole generally remained in good condition.

By using the CCS to re-enter and deepen the well, 655 m of hole had been drilled and valuable data recorded across a new and potentially valuable reservoir, previously undrillable by conventional means. During the operation, 522 connections without interrupting circulation had been made, while both drilling and tripping. Of these, 94% were in an average of 21 min, with less than 1% of NPT for the project attributable to the CCS. Following this success, Petrobel has retained the CCS for a similar operation in a second well being currently drilled.

The second commercial CCS was deployed by Statoil in March 2006 to drill a short, deviated section of a Kristen field well from the semisubmersible Scarabeo 5 in 360 m of water offshore Norway. Again, the ability to maintain uninterrupted circulation allowed Statoil to plan and drill an 8 $\frac{1}{2}$ -in. hole through a normally pressured zone below an open, possibly depleted reservoir section using the ECD to control the well rather than the static mud weight.

Utilizing the Continuous Circulation System ensured Statoil's HPHT overbalance requirements would be met in the event depletion in the open reservoir section above the target narrowed the pore pressure-frac pressure window to a point where conventional drilling techniques would not be permitted.

Utilizing the CCS also proved its viability for use on future projects when drilling parameters would not permit conventional drilling practices. In the event, 123 m of new hole were drilled from below 5,165 m, with 151 connections while drilling or tripping, with an average of 19 min/connection. There were no interruptions to circulation, and MWD data, including ECD, were recorded throughout.

Statoil has retained the system for development drilling operations on the Kristen field and has carried out make up and breakout tests with 4 $\frac{1}{2}$ -in. XTM50 drill pipe using the Ullrig test facility in Stavanger.

SUMMARY

The CCS has been successfully introduced to the drilling industry and has proved its reliability and value. It enables previously difficult-to-drill formations to be safely and successfully penetrated and valuable logging data to be recorded.

The engineering design, preparation and testing carried out by National Oilwell Varco, backed up by the data recording and reporting system and the Internet connection to the 24/7 Houston Engineering support facility have resulted in near "jet engine reliability" right from the introduction of the first system. A new and enabling technology has arrived.

This article is based on a presentation to be made at the 2006 LADC International Well Control Conference on 7-8 November in Abu Dhabi, UAE.

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