New tools, new knowledge drive UBD expansion

UNDERBALANCED DRILLING offers significant potential to lower drilling costs and minimize formation damage. But there is a need for greater understanding of the capabilities of underbalanced drilling and its limits.

At the 2002 IADC/SPE Drilling Conference, 26-28 Feb in Dallas, two sessions explore the potential of underbalanced drilling and solutions to technical and operating challenges.

Both sessions are chaired by **John E Boyle**, **Weatherford International Inc** and **Richard Reiley**, **BP plc**.

CONTRACTOR PERSPECTIVE

Underbalanced drilling techniques (UBD) are evolving at a fast pace as oil companies learn how to use the technology to maximize well production and lower finding costs.

The technology can be as simple as using a rotating head, drilling with water and flaring gas from low permeability, high-pressure gas reservoirs in Texas or Oklahoma. Or it can be as complicated as drilling with nitrogen generating equipment into an H2S-bearing oil reservoir in a horizontal well.

The common denominators in all of these operations—the basic drilling rig and the drilling crews—are the focus of IADC/SPE paper 74445, "Underbalanced Drilling—The Drilling Contractor's Perspective." The paper was prepared for the Conference by **R D Murphy**, **Parker Drilling Company International**; **M Hedge**, **BP plc**; and **P Thompson**, **Parker Drilling Company International**.

Parker and **BP Amoco** have drilled in the Cusiana Field of Colombia for the past several years and the exploration and delineation drilling is nearly complete. Wells in the area are deep, high pressure, high flow rate oil wells. BP Amoco is experimenting with different UBD techniques, equipment and rig configurations to further exploit the field.

The authors report that there are plans for sidetracking and drilling multilateral wells to enhance existing production. The changes to drilling techniques and the new equipment present a challenge to the drilling contractor to modify existing rigs, retrain crews and understand the new UBD technology in order to help the oil company drive down production costs, said the authors.

PERCEPTIONS, REALITIES

The oil and gas industry drills thousands of wells globally each year, but what makes a well "successful" depends to a large extent on the perspective of the assessor.

To the drilling engineer, a successful well is one that is safely drilled to target depth on time and under budget.

However, the production engineer would add to these criteria the need for minimum formation damage and maximum production potential.

Unfortunately these two perspectives can often be mutually exclusive due to the problems associated with the management of Equivalent Circulating Density (ECD).

That is a conclusion of the authors of IADC/SPE paper 74448, prepared for the Underbalanced Operations Session I by **D M Hannegan** and **R O Divine**, **Weatherford International Inc**.

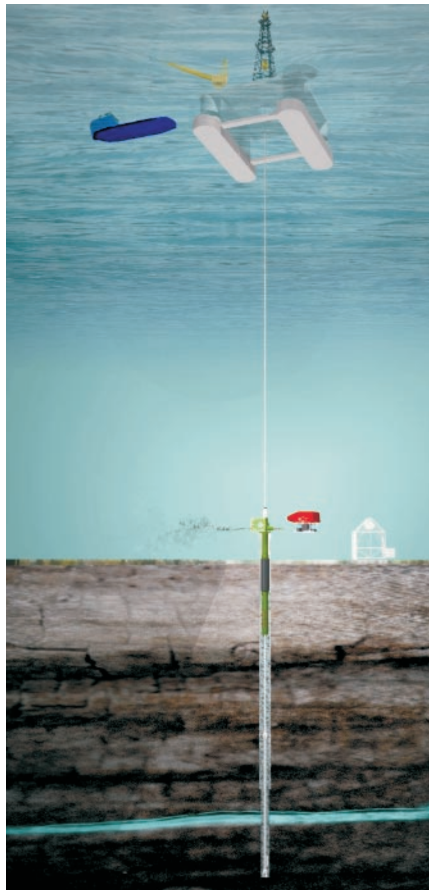
Title of the presentation is "Underbalanced Drilling—The Perceptions and Realities of Today's Technology in Offshore Applications."

Engineers have been taught that ECD is increased effective density caused by the frictional effect of fluid circulating in the annulus.

Today, however, the tools and technology associated with underbalanced drilling (UBD) have added an exciting and very beneficial dimension to ECD management, according to the authors.

Such capability is now viewed by most majors as required in many offshore situations to deal with depleted zones/reservoirs relative to water depth, narrow margins between fracture gradient and pore pressure, and for dealing with abnormally pressured aquifers (shallow water flow hazards).

Management of ECD is traditionally achieved by drilling with mud circulated under pressure and suitably weighted to drill within a margin of error until a casing point is mandated. This method has several benefits, the authors note, but it also carries with it several detriments.



Virtual riser concept helps deal with special pressure relationships in deepwater drilling.

Though it is accepted as the standard approach, 20-30% of the world's known offshore oil and gas resources cannot be economically drilled with today's tools and techniques.

The authors point out that UBD tools and techniques are key to several emerging offshore technologies, including drilling with subsea and surface BOP stacks with pressurized mud return systems; dual gradient deepwater drilling; and the use of subsea rotating diverter control heads to control shallow water flows when drilling without a riser.

The authors illustrate that in several offshore applications, UBD technology is not used to achieve a true state of underbalance at any point in the drilling program, but to drill safely nearer a balanced condition. That permits the operator to reach TD with fewer casing strings and with less costly drill ships, and to avoid invasive damage to the reservoir.

LIGHTWEIGHT FLUIDS

The use of lightweight fluids is an effective way of drilling through hard formations, depleted reservoirs and lost circulation zones.

Although practical experience is guiding technological improvement, the limited knowledge of the physical phenomena is leading to conservative design.

In this scenario, cuttings transport is not normally a major problem while drilling with lightweight fluids, due to the excessive liquid and gas flow rates pumped.

The 3-phase flow phenomenon involved is quite complex and reduced scale results are questionable, since dynamic similarity is difficult to achieve.

Based on that, a group of real scale tests was performed at the Petrobras training center.

IADC/SPE alternate paper 74464 reports on those tests and the conclusions reached. The paper, "Evaluation of Solids Carrying Capacity in Aerated Fluid Drilling—Real Scale Tests and Modeling," was prepared for the Conference by **A L Martins**, **A F Lourenco**, **P H Andrade** and **E Y Nakagawa**, **Petrobras SA**.

The Petrobras tests measured solids return time in a 1,270-m deep, 6.28-in. diameter vertical well. Solids return was measured by commercial equipment for sand production monitoring in production platforms.

The tests aimed to evaluate the cuttings transport capacity of lightweight fluids (air/water and air/XC polymer mixtures) at several flow rates.

The effects of gas/liquids rates, liquid phase rheology, back pressure, depth and particle size were evaluated based on the experimental path.

According to the authors, a mechanism of solids transport by aerated fluids, joining basic concepts of particle sedimentation in non-Newtonian fluids and gas-liquid flows, is proposed and implemented in Petrobras lightweight fluid drilling hydraulics software.

"... drilling with a bottomhole pressure less than the formation pore pressure will usually increase the risk of borehole instability due to shear or tensile failure of the rock adjacent to the borehole. The extent of rock failure is very sensitive to the pressure in the annulus..."

IADC/SPE paper 74447

This model is an important basis for the optimization of field operations, combining cost reduction and safety.

MODELING FLOW, WELLBORE

Underbalanced drilling techniques have been applied to avoid or mitigate formation damage, reduce lost circulation risks and increase penetration rate.

However, drilling with a bottomhole pressure less than the formation pore pressure will usually increase the risk of borehole instability due to shear or tensile failure of the rock adjacent to the borehole. The extent of rock failure is very sensitive to the pressure in the annulus between the drill pipe, collars or BHA and the formation.

The capacity of the drilling fluid and gases to effectively circulate cuttings and cavings to surface is also highly sensitive to the annular flow velocity.

In IADC/SPE paper 74447, the authors describe the coupling of two popular software packages—STABView and WELLFLO7—to solve the complex interaction of borehole instability, rock collapse, detachment and wellbore hydraulics during underbalanced drilling operations.

The paper, "Coupled Modeling of Borehole Instability and Multiphase Flow for Underbalanced Drilling," was prepared for the Conference by **P J McLellan** and **C Hawkes**, **Advanced Geotechnology Inc**; and **S Smith**, **Neotechnology Consultants Ltd**.

In particular, a profile of the average borehole diameter can be predicted that accounts for hole enlargement in weak formations, and its consequences for annular pressures and flow velocities.

The authors illustrate the use of these two models running in a coupled mode with several examples, including a case study of a sidetrack well that was drilled underbalanced using coiled tubing technology in western Canada.

In that case, underbalanced drilling was required to mitigate lost circulation problems that had previously been experienced in a severely depleted carbonate reservoir. However, severe tight hole problems and poor hole cleaning were encountered during drilling operations, and ultimately the bottomhole assembly became stuck.

Subsequent borehole stability analyses predicted that significant hole enlargement would have occurred in two weak, shaley intervals that were drilled at a high inclination in the build section of the well, according to the authors.

Wellbore hydraulics analyses showed that the flow velocities achieved in the enlarged intervals of this well were low, which led to an accumulation of cuttings and cavings, thus resulting in the stuck pipe.

NEW EM MWD SYSTEM

In IADC/SPE paper 74461, "Case History of First Use of Extended-Range EM MWD System in Offshore, Underbalanced Drilling," the authors discuss the first use of an Extended-Range Electromagnetic (EM) MWD system for underbalanced drilling in an offshore well.

The paper was prepared for the Conference by **D Weisbeck** and **G Blackwell**, **Computalog Drilling Services Inc**; and **C Cheatham**, **Consultant**.

Use of EM MWD in offshore applications has historically been limited, due primarily to the difficulty of seabed deployment of the receiving antenna.

In underbalanced drilling, however, EM is the MWD system of choice because mud-pulse telemetry has great difficulty operating in two-phase flow conditions commonly used.

As underbalanced drilling becomes more frequently used offshore, one of the limiting technologies is the difficulty for traditional MWD systems to provide real-time annular pressure, directional, and lithology data, according to the authors. In this paper, they describe the use of EM MWD on Well D12, drilled by **Maxus** offshore Indonesia using underbalanced drilling to prevent massive lost circulation and formation damage in the reservoir.

The authors report that the main reason for using EM MWD was to provide real-time data for:

- Annular pressure—Previous wells experienced massive lost circulation and extensive formation damage;
- Formation evaluation—The well reached TD early because basement was encountered higher than expected, as identified by EM MWD;
- Directional control—EM MWD reduces rig time for surveys because they are transmitted during connections while traditional MWD systems transmit surveys after connections, thereby increasing drilling time.

In addition to the challenges of using EM MWD offshore, other significant technical hurdles were overcome in Well D12 using the EM MWD system, the authors report.

Extremely low resistivity formation and high hole inclination angle (up to 73 degrees) required the use of an Extended-Range system using a dual antenna "piggy back" system to ensure getting the EM signal to surface reliably. Two different drilling fluids were used: 3% KCl gasified with nitrogen and diesel mist.

The well was successfully drilled and completed according to plan with the Extended-Range EM MWD system performing reliably and accomplishing all technical objectives.

PRESSURE PREDICTION

It is generally accepted that the success of underbalanced drilling (UBD) operations depends on maintaining the wellbore pressure between boundaries determined by the formation pressure, wellbore stability, and the flow rate capacity of the surface equipment.

Therefore, the ability to accurately predict wellbore pressure is critically important for both designing the UBD operation and predicting the effect of changes during drilling.

That is the conclusion of the authors of IADC/SPE paper 74426, "A New Comprehensive, Mechanistic Model for Underbalanced Drilling Improves Wellbore Pressure Predictions." It was prepared for the Conference by **C Perez Tellez**, **Pemex-Louisiana State University**; and **J R Smith** and **J K Edwards**, Louisiana State University.

Most of the pressure prediction approaches used in current practice for UBD are based on empirical methods, which frequently fail to accurately predict the wellbore pressure, according to the authors. Consequently, the current trend is toward increasing use of prediction methods based on phenomenological or mechanistic models.

The authors present an improved, comprehensive, mechanistic model for pressure predictions throughout a well during UBD operations. The model is composed of a set of state-of-the-art mechanistic steady state models for predicting flow patterns and calculating pressure and two-phase flow parameters in bubble, dispersed bubble and slug flow.

In contrast to other mechanistic methods developed for UBD operations, the model takes into account the entire flow path including downward two-phase flow through the drill string, two-phase flow through the bit nozzles, and upward two-phase flow through the annulus.

Additionally, more rigorous, analytical modifications to the previous mechanistic models for UBD give improved wellbore pressure predictions.

The results of using the new, comprehensive model were validated against two real wellbore configurations with different flow areas. Field data from a Mexican well, drilled with the simultaneous injection of nitrogen and a non-Newtonian fluid, and full-scale experimental data from the literature validate the improved model predictions, the authors report.

CUTTINGS TRANSPORT

Many studies have been conducted to determine the optimal hydraulic conditions when conventional drilling fluids are used. However, little information is available for cuttings transport when gasified fluids are used as a drilling fluid.

Since deviated and horizontal drilling are becoming more common and frequently use non-conventional drilling fluids such as gasified fluids or aerated muds, a better understanding of the cuttings transport phenomena is needed for this application.

In IADC/SPE paper 74463, "Determination of Minimum Air and Water Flow Rates Required for Effective Cuttings Transport in High Angle and Horizontal Wells," the authors report on efforts to gain this understanding. The paper was authored by **P Vieira**, **PDVSA**; **S Miska** and **T Reed**, **University of Tulsa**; and **E Kuru**, **University of Alberta**.

The study described by the authors was conducted to help gain more in-depth understanding of cuttings transport in horizontal and highly inclined wells when using gasified fluids. Extensive experiments were performed in a unique field-scale low-pressure flow loop (8-in. x 4.5-in., 90 ft long) at horizontal and at an inclination angle of 80 degrees from vertical.

Gravel with 3.29-mm average diameter was used to simulate drill bit cuttings and water and air were used as the liquid and gas phase, respectively. The three phases were injected into the test section of the flow loop, at different volumetric flow rate combinations, for the horizontal and 80 degree inclination angle.

The effects on cuttings transport of gas and liquid flow rates, drilling rate, inclination angle, pressure drop and flow patterns were analyzed.

According to the authors, for the range of volumetric flow rates used during these tests, cuttings are only transported by liquid phase. It was also found that it is possible to define a boundary for the minimum air and water velocities required to avoid the formation of a stationary cuttings bed. These minimum requirements exist in the intermittent region for the gas and liquid interface distribution.

The minimum requirements for air and water injection rates are also a function of the solids injection rate. The authors postulate that there is a minimum energy required for solids transport, and it is constant for a given solids injection rate. The inclination effect for angles close to horizontal is negligible.

An empirical equation was developed to determine the minimum gas and liquid volumetric flow rates required for effective cuttings transport in high angle and horizontal wells. ■