Low risk, high reward drives underbalance for PDO

PETROLEUM DEVELOPMENT OMAN (PDO) has invested in a campaign approach to underbalanced drilling by taking a low-risk/high reward approach to implementation. This approach has paid off in that promising increases in production have been seen.

In one of the campaigns this benefit was not seen until the seventh well following optimization of practices. These benefits would not have been observed in the 1-3 well trials that are typical for UBD projects. The other benefit of a multi-well campaign is that clear learning curves can be demonstrated for well times, move times and NPT reduction.

In addition to the immediate benefits of increased production, UBD has been demonstrated as being a tool for reservoir evaluation and real-time decision making on well operations and completion. It also acts to bring petroleum engineering and well engineering staff closer together for decision making as real-time production data is produced while drilling.

As new, previously unknown information is obtained about the reservoir it also acts as a catalyst for challenging existing well and completion designs.

Due to the encouraging initial success the UBD campaign has been extended for a further one and a half string years and new UBD candidates are being pursued. In addition to UBD scope for UB workovers and UB side-tracking using ultra-short radius technology is being pursued.

UBD WELL DESIGN ISSUES

The primary driver for the application of UBD in Saih Rawl was the minimization of reservoir impairment. This defined the cornerstone from which a basis of design would be developed.

The final design, therefore, would be one in which both the induced bottom hole parameters and the UB surface equipment result in an underbalanced state at all times during drilling

The Saih Rawl wells drilled conventionally were multilateral designs, with 3-5 legs per well, drilled from a common, 7-in. cased, horizontal backbone. Due to the overall reservoir exploitation plan, there was no flexibility in changing this design for the UBD trial. As such, the well design had to ensure that underbalanced conditions could be achieved and maintained throughout the long horizontal legs.

In the case of drilling the longest legs, this meant that the horizontal section (open hole and backbone combined) could be in excess of 2,500 m, with 1,700-2,000 m of open hole.

For the start-up phase of the project, the design had to work within the limitations of mud pulse MWD telemetry. The geology of the Saih Rawl area does not permit the transmission of electro-magnetic (EM) MWD signals without using an extended reach method.

The two proven methods of EM transmission that could have been applied were each eliminated based on potential operational challenges with running wireline antennas in the drillpipe, or running numerous repeaters in the drillstring.

Crude oil was chosen as the liquid phase of the two-phase drilling fluid system. The use of crude oil would minimize formation damage, which was the primary objective for applying UBD technology in this pilot project.

Initial well design focused on the use of the native crude system, but due to logistics, another crude oil (Sayyala) was used to start the UBD operation.

Saih Rawl well candidates were located close to existing gas lift infrastructure. After two-phase flow simulations showed that the wells could be drilled underbalanced with the use of natural gas as the service gas, the decision was made to utilize the lift gas for the Saih Rawl UBD project.

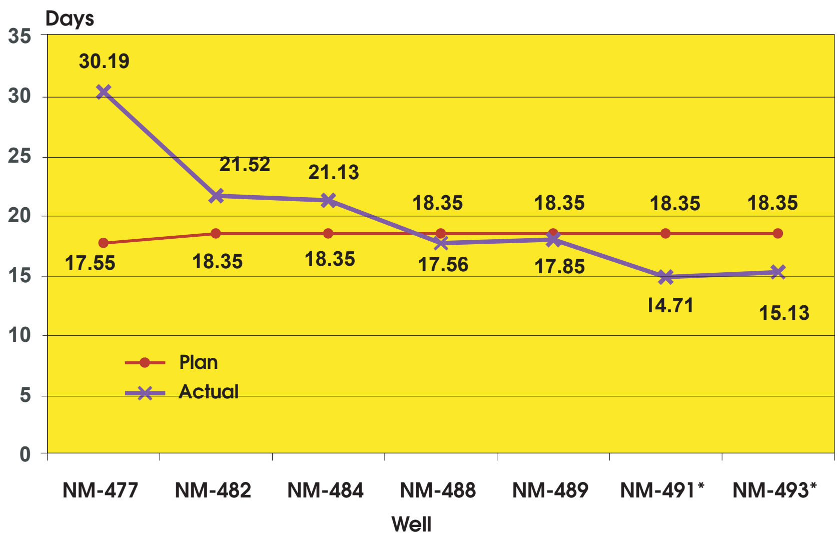
The use of natural gas was ideal logistically, but presented additional safety concerns that had to be addressed throughout every stage of the well design process.

With the use of mud pulse MWD tools, the clear choice for gas injection method was to install a 7-in. concentric casing string and inject the gas down the annulus created by the concentric casing string and the 9 5/8-in. casing. This minimized the gas rate required to be injected through the drill pipe to maintain underbalanced conditions on the very low pressure candidates, reducing the potential for problems when surveying or transmitting other data with the use of the mud pulse tools.

Without concentric casing gas injection, the fluid slugs take longer to circulate out of the hole after a connection is made. The resultant pressure spike is larger, often resulting in an overbalanced condition.

The long horizontal length of these wells

Learning Curve for Nimr UBD wells



and the potential high oil production would have made the spikes especially severe without the use of concentric casing gas injection.

Two-phase flow modeling showed that the very low pressure candidates could not be drilled underbalanced throughout the desired length with the use of concentric casing injection alone.

Calculations using a combination of concentric and drill pipe gas injection showed that underbalanced conditions could be maintained throughout the horizontal section using this method, even on the longest legs of the lowest pressure candidates.

Surface equipment consisted of a rotating control head (RCH), primary and secondary separator, centrifuges and stock tank farm. The secondary separator was operated at low pressure (+/- 140 kPa) to ensure that most of the gas in solution in the oil from the primary separator (690 kPa) would break out of solution.

Finally, the oil was processed from the secondary separator through two centrifuges to remove solids, and then shipped to storage in closed and vented atmospheric tanks. Produced oil was pumped to the production facility so that excess storage capacity on location could be minimized for safety and logistic reasons.

OPERATIONAL ISSUES

The first UBD trial in Saih Rawl was a Penta-Lateral producer well. Laterals were placed a meter or so below the roof of Shuaiba formation geo-steering using resistivity and gamma tools. The first three legs were drilled conventionally overbalanced. The fourth and fifth legs were drilled underbalanced. The well was drilled using a rig with a Kelly, i.e., no top drive was used.

No problems were experienced drilling in sliding mode for the first 800 m but after that there were difficulties in getting back to bottom and getting the Kelly-bushing back in place after making connections without rotation. The problem became aggravated until it became impossible to slide.

The problem was due to lack of weight in the drill string to push the BHA and drill pipe in the horizontal open hole section exacerbated by the 7-in. concentric casing string making the use of 3 ½-in. HWDP the only option due to annular pressure considerations.

Attempts were made to make the string stiffer by mixing DP and HWDP, however not much improvement was seen. The 3 ½-in. 15.5 ppf DP was replaced with 13.3 ppf and a BHA excitement tool.

However, leg #4 was called TD early due to lack of directional control. In leg #5, two BHA excitement tools, one above the BHA and the second one 850m above the BHA, were employed to attempt to transfer weight more effectively.

Placement of the BHA excitement tool 850m above the BHA appeared to make a lot of difference. Oriented drilling was achieved without problem, however, the leg was TD'd early for geological reasons (formation dipping).

The second well in the campaign was a tri-lateral producer. Approximately 500 m of the first lateral was drilled and a high water cut observed. A decision on the next step was pending. Real-time decisions can be made using UBD, potentially saving the cost of wells drilled into unproductive/faulted or watered-out zones.

SAIH RAWL UBD RESULTS

Clear, unambiguous improvement in PI was seen as a result of inflow tests conducted after reaching TD in Legs 3 (OB), 4 and 5 (UB). Productivity Improvement Factor (PIF) in leg 3 was 1.16, 1.86 in leg 4 and 1.8 in leg 5. This may be the most direct evidence of the impact of drilling underbalanced compared to overbalanced as the legs are just 80 m apart.

Leg #3 has higher productivity than the field average. This may be due to the fact that the leg was circulated to crude and flowed immediately after being drilled. Usually legs are suspended in brine until the well is hooked up.

NIMR UBD CAMPAIGN

The Nimr field is being developed by horizontal wells with laterals of about 500 m, completed with wire-wrapped screens for sand control.

The evaluation phase focused on the factors that affected the ability to maintain UBD conditions throughout the duration of the well.

The target UBD bottom hole circulating pressure (BHCP) was established as 10-20% below reservoir pressure. This drawdown was established for several reasons. Reservoir inflow needed to be controlled due to the higher density and viscosity of the Nimr crude.

The density and viscosity would have a negative effect on maintaining UBD conditions. The presence of H2S was also a driver in limiting inflow; this would reduce the risks associated with exposure to personnel and equipment.

Water coning, wellbore stability and fines migration were also identified as reasons for establishing the drawdown limit.

The drilling liquid medium had to be compatible with the reservoir. The initial flow analysis evaluation was conducted with a 35 API diesel as the drilling liquid. Diesel was determined to be poor at maintaining UBD conditions and dismissed as a potential fluid.

Crude oils available within PDO were also evaluated as candidates. Once evaluation was complete, Sayyala crude was identified as the most suitable candidate.

As reservoir compatibility was a key issue, a conscious decision was made to avoid the addition of chemicals such as corrosion inhibitors, demulsifiers, etc.

If problems were observed then chemicals could be added in subsequent wells. No additives were found to be required in later wells.

The drilling gas medium utilized was on-site membrane-generated nitrogen. The lower specific gravity of natural gas versus nitrogen would have been beneficial in establishing the desired BHCP.

However, the logistics involved in delivering it to the well site made it uneconomical for the short duration wells planned for the Nimr project.

The gas injection method chosen was via concentric casing. The use of mud pulse telemetry for directional drilling was the primary rationale for using concentric injection.

Although a percentage of gas can be introduced into the drill pipe and a signal maintained, if more gas injection was required it could jeopardize UBD conditions for the sake of downhole communication.

The importance of controlling reservoir production was deemed as paramount for maintaining UBD conditions. It was established that the viscosity effect of Nimr crude on the circulating system increased exponentially as its ratio in the wellbore increased linearly.

A liquid volume percentage of only 30% Nimr crude was determined to be enough to create near balance conditions due to increased friction losses and equivalent circulating densities.

IMPLEMENTATION PHASE

The control of return fluids is the primary function of the UBD package. The package must be able to control the pressure, volume, type of gas and temperature associated with the produced fluids of the targeted reservoir.

This control was accomplished with the use of a rotating control head, a double block and bleed choke manifold and a pressure separation vessel.

The separation of the return fluids was a critical operation for the project. Sayyala crude was recycled and re-injected down the drill string, so special attention had to be paid to possible contamination of solids and produced crude.

The solids control was to prevent damage to the BHA components, control density and remove a potential reservoir impairment device from the circulating system.

A closed loop centrifuge system was incorporated downstream of the pressure separator to deal with solids control. It had the ability to re-circulate the drilling liquid from most of the storage tanks on site.

Managing surface fluids was recognized as an important process in achieving project goals. Two of the four stock tanks were used exclusively to provide the retention time necessary to allow gravitational separation of the Sayyala and Nimr crude.

Maintaining UBD conditions during all phases of the project was one of the primary goals in developing the Nimr field. It was also recognized that the implementation of a UBD campaign would require a step-wise approach to manage risk. This is the reason that, although UBD conditions were to be maintained while drilling the reservoir section, once a trip was required the well would be circulated clean and then allowed to balance itself.

This also applied to the time at which TD would be called and the wire-wrapped screens were to be run to complete the lateral section.

Considerable emphasis was placed on HSE issues during the implementation phase of this project.

Not only were the usual concerns of a UBD project brought to the forefront but also the additional hazards associated with H2S production and using a drilling liquid that is categorized as flammable.

These factors established that it would be necessary to use a closed loop system for this project.

Special attention was paid, but not limited to, emergency control systems, release points, ignition sources, PPE, fluid handling procedures and rig/UBD contractor interfaces.

OPERATIONAL ISSUES

A typical learning curve was seen during the first wells with an initial well time of 30 days reduced to 15 days by the sixth well. Several operational difficulties caused delays during the first wells.

Rig-up and down of the UB equipment was on the critical path of the operation during the first well. After the second well, however, the equipment could be rigged up/down while the rig was drilling the non-reservoir section of the well without interruption.

Severe sliding problems were observed during the first well and friction factors were back-calculated from the readings for comparison with a conventional well. It was not clear if the increased friction was caused by insufficient hole cleaning or due to the fact that there was no mud-cake present.

At the end of the well it was found that considerably more cuttings were generated than theoretically expected, pointing to a possible hole-cleaning problem.

Due to the poor rheological properties of the drilling fluid, difficulties with cuttings transport both downhole and in the surface system were expected in the design phase of the project.

The problem, however, proved to be more severe than expected and severe cuttings dropout was observed in the surface facilities. Two wells had to be cut short because of this problem.

While drilling, severe BHP fluctuations were observed causing periods of over/under balance. These were thought to be caused by the concentric annulus unloading, changing the gas/fluid ratio and causing the well to slug.

Several parameters and procedures were varied and the problem solved by controlling BHP on the choke in a similar way to conventional well control methods for circulating out a gas kick.

During the campaign, however, new dynamic transient flow modelling software became available that was able to predict the dynamic behavior of a given UB system allowing stable conditions to be maintained.

The model was validated with the data already available and is now used to provide an engineered solution in the planning phase of UB wells.

It is of vital importance to the success of UBD to know the reservoir pressure. Measuring the reservoir pressure at the beginning of the section to establish the correct reservoir pressure and then re-measuring during drilling of the well is important. This is especially true if the well is drilled in an area where other wells are already producing in order to avoid drilling overbalanced in depleted areas.

Due to the completion design, the amount of post-completion measurements that can be taken from wells in the Nimr field are very limited. Pressure and flow measurements over the horizontal section are very difficult and expensive so very limited data is available. UBD allows for measurements to be taken in the pre-completion stage.

Several wells are drilled through different sub-crops but there is no clear understanding which of the two sub-crops contributes to the production of the wells.

With UBD, well-testing can be done while drilling and differences in pressure and productivity can be measured. The value of information obtained by UB almost justifies the operation in certain cases, which is often overlooked when writing the business proposal for UB.

REFERENCE

This article is based upon SPE/IADC paper 79853, *Low Risk/High Reward Strategy Drives Underbalanced Drilling Implementation in PDO* by **P A Francis**, **W Geldof** and **S Harthi**, **PDO**; **I A Davidson**, **Shell GIT**; and **M S Culen, Northland** and **T Jenkins**, **Weatherford**. ■