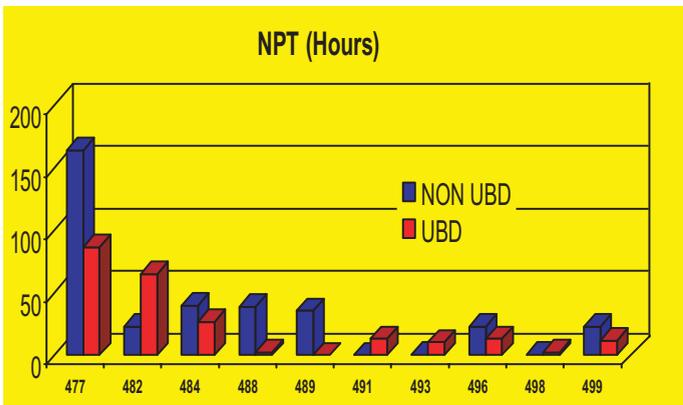


# UBD used to exploit reservoirs in Nimr field in Oman

**IN MAY 2002**, Petroleum Development Oman (PDO) embarked on a 10-well, underbalanced drilling (UBD) trial campaign in the Nimr field using crude oil as the drilling fluid and membrane generated nitrogen as the lift gas. UBD was proposed as a productivity improvement technique for the Nimr field following a low risk/high reward analysis.

The Nimr field is a complex of six fields. UBD was implemented in the Nimr A field consisting of two reservoirs, the Amin and Al Khlata, which are generally high permeability (+1 Darcy) sandstone reservoirs containing medium gravity (210 API) viscous (300-500 cP) crude.



Horizontal wells are generally completed with a wire-wrap screen (WWS) across the reservoir section due to sand production history in some wells, and are produced via artificial lift methods, primarily beam pump. Although the predominant factor affecting net oil rate performance was the rate and behavior of water cut development it was suspected that drilling-induced skin, combined with mechanical skin from the completion, was a contributing factor to recent poor results from the horizontal wells.

## NIMR PROJECT

Nimr is actually a complex of six fields. UBD was implemented in the Nimr A field which is a large "turtle-back" structure primarily composed of two reservoirs beneath the Nahr Umr shale cap rock: the Haima Amin (Cambrian, Aeolian dune) which is the primary reservoir, and Al Khlata (Permian, glacial) which is eroded into the Amin and is present along the faulted flanks of the

field. The Amin and Al Khlata both have reservoir permeability of >1 D in the better quality sections. The Amin contains small cement streaks within the section, which may cause local baffling. The Amin also has 10-30+ m thick sections of weathered zone, which is of lower quality, permeability and oil saturation than the "good" Amin. The Al Khlata has been shown to have a high degree of lateral variability but is generally good quality over most of Nimr A field.

The existing field development strategy places horizontal wells with +1,400 m laterals 3-5 meters below the top of the reservoir. A typical completion is 4 1/2-in.

WWS inside 6 1/8-in. reservoir section with beam pump for artificial lift. The primary grid spacing is 172 m and current infill spacing is 86 m. The field is near completion of primary development, with only flank (lower oil column) locations remaining. Recent new oil well performance (1999-2001) had consistently performed lower than expectation. Infill drilling commenced in earnest during 2002.

For the 10-well trial, intermediate 7-in. liner was set at 90° inclination within the target window (4-5 m below the top of the reservoir) and the lateral reservoir section was drilled underbalanced at 90° inclination with a +/- 2m vertical window.

The original plan was to drill UB with an equivalent circulating pressure 1,500-2,000 kPa below expected reservoir pressure. The primary driver for limiting the drawdown was concern about wellbore stability.

To meet the underbalanced well objectives, extensive steady state multiphase flow modeling and compatibility testing indicated that crude oil in combination with gas lift was the appropriate drilling fluid. Membrane-generated deoxygenated air was selected as the lift gas in pref-

erence to cryogenic nitrogen for economic reasons. After evaluating a number of native crude oil alternatives, Sayala crude was selected as the base drilling fluid due to its low density (0.78 sg) and low viscosity (30 cP). A concentric annulus (9 5/8-in. X 1-in.) design was chosen for lift gas injection, primarily due to the incompatibility of mud pulse telemetry measurement while drilling (MWD) and drill pipe injection of the high volume of lift gas required to maintain underbalanced conditions. MWD was used to transmit directional, bottom hole pressure (BHP) and petrophysical data, etc. Electromagnetic Telemetry MWD was considered but evaluated as uneconomical for this trial.

## UBD SURFACE PACKAGE

The UBD surface package consisted of the following equipment:

- A 13 5/8-in. 5,000 psi Passive Type Rotating Control Head (RCH) rated for 2,500 psi operating pressure, installed on top of the 11-in. 5,000 psi conventional BOP stack to provide the annular pack off around the drill pipe and tool joints while drilling and tripping,
- The conventional BOP stack consisted of an annular, variable pipe rams and blind/shear rams,
- 7 1/16-in. 5,000 psi ESD valve was installed on the outlet of the RCH,
- 7 1/16-in. 5,000 psi flanged Schedule 160 flow line to the choke manifold,
- 7 1/16-in. 5,000 psi flanged choke manifold c/w 3 1/8-in. 5,000 psi double block and bleed choke and valve legs with Schedule 160 piping,
- 7 1/16-in. 5,000 psi Schedule 160 piping Sample Catcher c/w 2 1/16-in. valves on dual sample legs,
- Separation vessel rated for MA WP of 180 psi and capable of handling gas rate of 55 MMscf/d and a liquid rate of 20,000 bpd @ 150 psi,
- 6-in. flare lines with WECO 206 hammer unions to a flare pit,
- 200 bbl (30 m3) solids settling tank c/w degasser unit,
- 2 - 750 gallons/min solids centrifuges,

- 4 - 400 bbl horizontal oil storage tanks for the fluids handling system.

## HSE

After the contract was awarded, considerable effort was expended to ensure UBD related HSE issues specific to the project were clearly understood by all stakeholders. Not only were the usual hazards and concerns regarding UBD highlighted and addressed, but project specific hazards such as potential for H<sub>2</sub>S, the use of a low flash point crude as the drilling fluid and the extreme ambient temperatures associated with summer work in a desert environment were identified and also addressed. In addition, equipment and procedures proposed by the project team and vetted during HAZOP exercises for operational and HSE effectiveness, also had to comply with PDQ's HSE Management System.

The primary project objectives were HSE (do it right, but do it safe the first time) and technical (demonstrate and prove the benefits of UBD for the Nimr reservoir and PDO in general). Project economics were important but secondary (economics would be fine tuned as the project progressed).

## UBD PROCEDURES

This was the philosophy that was used as a benchmark for resolving conflicting objectives as the project evolved to the execution phase. It was the primary reason for the closed loop system, the solids handling system, well-control procedures, tripping and other operational procedures.

Maintaining UBD conditions during all phases is one of the primary goals for PDO and this was reflected in the base case procedures. Nimr is classified as an IADC Level 1 UBO Type operation (Well incapable of natural flow to surface. Well is "inherently stable" and is low level risk from a well control point of view). It is recognized that whenever a UB drilled well is shut-in for any reason, it will continue to inflow until the shut in pressure plus the hydrostatic pressure is balanced by the formation static pressure. This principle applies regardless of reservoir pressure regime (normal, over pressured or depleted) or whether the well is shut in at surface or down-hole (down-hole shut-in effectively removes a portion of wellbore storage).

The procedure for Nimr was to maintain UB conditions while drilling in the reservoir. When it was necessary to trip pipe, the well would be circulated clean and allowed to balance itself after injection gas is shut off. The fluid level in the well was monitored using a sonic echo-meter. The same principle would be applied for tripping at TD. Running the WWS to complete the lateral section would also be conducted in a balanced well. Once again fluid level was monitored and when it stabilized, the WWS was deployed and the completion equipment installed.

## CONTINGENCY PLANS

PDO also supports the philosophy that a robust contingency plan must be in place for an IADC UBO Classification Level one level higher than the base case classification for the planned operation. It was decided that once the UBD campaign was running effectively, a down-hole deployment valve (DHDV) would be installed and run as part of the 7-in. tie-back concentric string. This would mitigate the requirement for well killing or a snubbing unit in the event the well proved capable of sustained flow of hydrocarbons to surface and/or creating pipe-light conditions while tripping.

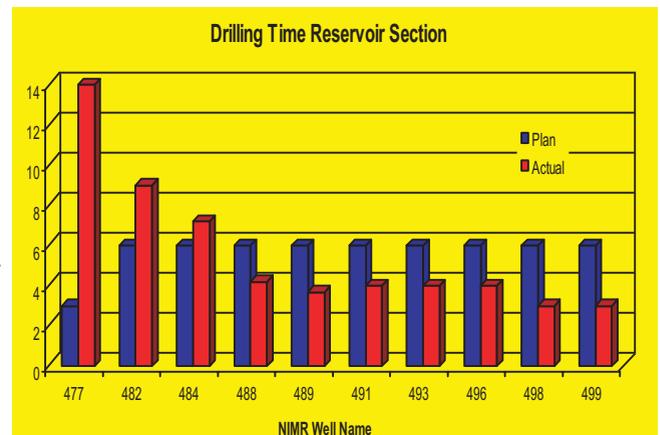
However, until a DHDV was available, a step-wise approach would be used. The contingency plan called for the well to be balanced with filtered brine if necessary to allow for tripping and the running of WWS. It was recognized that this was a potential source for formation damage and could negatively impact the evaluation of UBD as a reservoir enhancement technique. The operations team decided to use this technique on the first few wells until they were comfortable with at-balance tripping.

## OPERATIONAL CHALLENGES

During start-up of most new projects, the operations staff face issues of varying complexities either not considered or underestimated in the planning and

design phase. The Nimr UBD project was not an exception in this regard. Rig-up, commissioning and rig down of the UB equipment was on the critical path of the operation during the first and second wells. The sheer volume and complexity of the equipment coupled with personnel new to the equipment and therefore unfamiliar with the specifics of rigging up this particular package, is demonstrated by the typical learning curve. After the second well, the equipment was rigged up/down off the critical path while the rig was drilling the top-hole section of the well.

There were a number of challenges while drilling the first well that resulted in excessive non-productive time (NPT).



The primary one was cuttings transport (both down hole and in the surface system) and which may have exacerbated the other issues observed. Due to the poor rheological properties of the drilling fluid, cuttings transport was identified as a potential problem area during the design phase of the project but it was anticipated that once the well started to produce the higher viscosity Nimr crude, the problem would be reduced. This concern was justified and the problem proved to be more severe than expected. Severe sliding problems and increased torque and drag parameters were observed while drilling and it was suspected that this was a result of insufficient hole cleaning. This led to efforts to control the ROP by intentionally reducing it, with short wiper trips and increased circulation time prior to connections to aid in cuttings removal. This is believed to have caused localized washouts to occur, whereas hole stability was originally suspected.

This also resulted in increased direc-

tional work (sliding) to maintain hole angle, which leads to additional cuttings bed build-up, causing increased torque and drag. Severe cuttings dropout was also observed in the surface equipment.

The sparge system proved inadequate for the amount of cuttings and the transfer system clogged up. This finally led to a decision to shut down and clean out the solids from the separator and settling tank. Reoccurrence of the solids dropout problem in the surface equipment led to an early TD of the first two wells.

In addition to fighting the solids dropout problem, severe BHP fluctuations were observed while drilling. The accumulator affect caused by the charging and discharging of the concentric annulus resulted in the gas/fluid ratio above the gas injection point to vary by extremes and therefore, the well to slug/unload excessively.

This is a known phenomena usually solved onsite by trial and error (varying

several drilling and injection parameters and while adjusting the surface backpressure). Controlling BHCP with separator backpressure solved the problem on the first well. The choke was used on the second well and on subsequent wells reverted back to controlling with separator backpressure.

However, this is a tedious process and often results not only in NPT but also in periods of the well going overbalanced, as was the case on the first two Nimr wells.

Failure of conventional drilling equipment has also resulted in unplanned well kills and related NPT.

A key element in successful application of underbalanced drilling techniques is the amount of draw-down that the formation will be exposed to during the process. This can affect many of the design parameters included but not limited to pump rates, gas injection rates, injection gas volume required, storage tanks requirement and flare volumes. It

can also have an impact on borehole stability and fluids/solids handling at surface.

The importance of accurately knowing the static reservoir pressure cannot be overstated. For Nimr, the static reservoir pressure varies throughout the field and up to date static BHP measurements are not easily available because of the complexities of the beam lift system.

During the trial, static pressure was measured after drilling 20 m of reservoir section. The drawdown was applied relative to this pressure. This procedure was followed until the fourth well, when the phenomena of localized depletion was observed.

It had been observed that by re-measuring the static reservoir pressure while drilling, the static pressure measured at the heel may be higher or lower than at the mid-section. The pressure can be different again at the toe (TD).

## OPERATIONAL LEARNING

Throughout the trial, the principle of continuous improvement was used to optimize ongoing operations, reduce NPT and lower the unit cost of the project.

The 13 <sup>5</sup>/<sub>8</sub>-in. RCH was replaced with an 11 <sup>1</sup>/<sub>16</sub>-in. RCH. The RCH bowl is installed on top of the BOP as part of the stack rig up.

A special bell nipple adapter was built, which made it convenient to switch from conventional mode while drilling top hole to the underbalanced mode simply by removing the adapter nipple and replacing it with the pack-off and bearing.

This facilitates installation and pressure testing of flow lines and the UB surface equipment off the critical path while drilling top hole.

To improve drilling performance, the BHA was redesigned. Twenty 4 <sup>3</sup>/<sub>4</sub>-in. DC's were added above the 3 <sup>1</sup>/<sub>2</sub>-in. drill pipe to stiffen the assembly while orientated drilling. The short bearing pack motor used on the first well was replaced with a more conventional design (standard bearing pack with 7/8 lobe design).

To improve solids handling at the surface, the pump capacity of the sparge system in the separator was increased and the process flow was modified slightly. On the second well the process flow was directed from the separator to a settling tank (one of the horizontal 400 bbls tanks in the active system on the tank farm).

The curved bottom allowed more effective processing of solids while drilling the well. The suction for the centrifuges now comes from the bottom of this settling tank and discharges into the process tank.

Excess unprocessed fluid is pumped from the settling tank into the first section of the process tank as before. The remainder of the process is as described before.

To mitigate issues related to cuttings transport, a 65/35 blend of Sayala and processed Nimr crude was used as the kickoff drilling fluid after the second well. This has been optimized in time to a 50/50 blend currently in use and the

practice of dilution continues. This change, combined with the modified process flow, appears to solve most of the solids-handling problems.

More stringent attention to QA/QC of conventional drilling equipment and continuous improvements to the drill string design have also contributed to reduction in NPT.

To mitigate the NPT associated with BHP instability resulting from well slugging, a transient flow simulator (Ubitts) has been utilized to investigate design and operational parameters, which influence this behavior when using concentric casing gas injection.

Although this tool is designed as a training simulator, it is also now used to predict this behavior as the well is drilled and the appropriate action is taken to minimize the effect on the operation.

The practice of loading the well with brine prior to trips is no longer done as the procedure for monitoring fluid level in the well with the sonic echo-meter is effective and has been accepted by the operations staff.

The procedure for tripping pipe has been modified. The well is circulated clean, but gas injection continues and the well flowed while the pipe is stripped back to the shoe. At the shoe, the well is circulated and flowed until it cleans up (1 <sup>1</sup>/<sub>2</sub> times hole volume is produced).

This effectively allows the well to balance itself after injection gas is shut off but with native Nimr crude from the formation in the open hole section rather than drill fluid. The driver for this is that no potentially damaging drilling fluid is left in the open hole while tripping.

To improve data gathering while drilling, an additional bank of membranes was added to the gas generation process to allow more flexibility in managing drawdown.

We are still not capable of identifying small changes to productivity as we drill but we are sure we are underbalanced on the basis of gross productivity increases as we drill and from instantaneous production increases due to geological features (sweet spots).

There is an ongoing effort to identify whether the pressure decline observed as we drill is due to the heel toe effect or

from localized depletion from potentially drilling into a pressure sink created from producing wells in the area.

This impacts project economics (Acceleration vs. Incremental reserves recovery).

## CONCLUSIONS

Surveillance of horizontal wells is notoriously difficult. Determining precisely where early water breakthrough is occurring in horizontal wells with completions (WWS in open hole) and reservoir properties possessed by fields such as Nimr is more difficult still. UBD technology has enabled PDO to characterize reservoir flow units and determine the root causes of early water production.

The data collected from NM496 HI & H2 and NM498 clearly illustrate the potential to reduce field water to oil ratio (WOR) and improve ultimate recovery using UBD technology in combination with other technologies that can efficiently and reliably control water inflow upon initial completion.

UBD technology has been effective at exposing the dangers of incorporating simplifications in geological reservoir models when trying to locate unswept oil volumes. The learning and concepts applied to Nimr A field have relevance to a wide variety of reservoir settings.

The success of the campaign has been due to the multiwell campaign approach, persisting with the implementation through inconclusive start-up results that are typically associated with introducing new technology.

The initial goal of the campaign, to increase productivity, while having some success, has been superseded by the increase in reservoir understanding, which has led to successful water shut-off and will lead eventually to higher ultimate recovery in Nimr and elsewhere in PDO.

## REFERENCE

This article was adapted from IADC/SPE 81623, *The Nimr Story: Reservoir Exploitation Using UBD Techniques*, by **J Ramalho, Shell UBD Global Implementation Team; R Medeiros, PDO; P A Frances, PDO; and I A Davidson, Shell UBD Global Implementation Team.** ■