A milestone in directional operations: Drilling 1,000 horizontal wells in Oman

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BAKER HUGHES COMPLETED its 1,000th horizontal well for **Petroleum Development Oman (PDO)** on 3 Aug, 1998, with the drilling of the well Basma 8. This drilling milestone represents some 1.8 MM m of horizontal hole achieved over 8 years. Baker Hughes has provided all horizontal drilling services.

PDO is an oil and gas exploration and production company operating in Oman on behalf of its shareholders, the Omani government, **Shell, Total and Partex**. PDO's concession area covers most of the onshore acreage in Oman. Current PDO production is about 860,000 bbl/day.

8-plus years of horizontal drilling: Baker Hughes began drilling horizontal wells in Oman in 1990. Well designs have since evolved, as has the equipment. In February 1999, Baker Hughes brought the first coiled tubing drilling rig to Oman. The fully automated Galileo 3 is able to deploy drilling and work coil strings as well as handle pipe via a conventional mast.

The use of horizontal drilling technology has increased production fourfold over that previously achieved from vertical wells. Currently PDO completes around 20 horizontal wells per month.

DESIGN EVOLUTION

The design of horizontal wells has evolved considerably since Baker Hughes drilled its first well for PDO in 1990. The first wells drilled were simple shallow wells with short horizontal sections (300-700 m, with a true vertical depth of around 1,000 m and total measured depth of 1,600-1,700 m) These wells were designed with a low build rate up to a maximum of 8°/30 m.

The Saih Rawl 23 well was the first horizontal well drilled by Baker Hughes in Oman. This well reached a total measured depth of 1,800 m with a TVD of 1,200 m. The horizontal section was 600 m and the well took 18 days. Hole size in the lateral section was 8 ½ in. Two trips had to be made while drilling the build up section due to limitations in achieving the build rate required with the downhole motor technology then available, a standard Mach 1C motor and a standard collar based Directional Gamma MWD tool.

This contrasts markedly with the way horizontal wells are currently designed and drilled. The Lekhweir 310 well was drilled in October 1998 to a total measured depth of 4,621 m, with a horizontal section of 3,210 m. The build up section was drilled in one trip and the well TD'd in 24 days. Hole size in the lateral section was 6 ⅛ in. It took only 11 days to reach the 1,800 m drilled depth of Saih Rawl 23, a decrease in drilling time of 38%. A Mach 1X Ultra Series motor, thruster and probe based Directional gamma MWD tool were used to drill and steer this well. This well has the longest horizontal section in Oman.

The early wells were single producers typically kicked off high above the reservoir with low build up rates (up to 8°/30m) and a short horizontal section, Today, wells are drilled with an average build up rate of 13°/30m. Wells drilled today vary from single long-reach lateral to dual lateral and multilateral producers and injectors. The steerable limits of MWD tools and motors have evolved to enable us to rotate tools through the high build up rates required to lower kick off points and land early in the reservoir.

MULTILATERAL WELLS

As horizontal drilling technology developed, more challenging well designs were made to meet the requirements of PDO. Dual lateral, short-radius, slimhole (3 ¾-in.), long-reach multilateral wells and multi-branch wells with 5, 6 and 7 legs were designed and drilled. Reentry of old vertical wells using the latest window cutting technology has become common practice. In 1998 approximately 75% of horizontal wells drilled were multilateral wells.

A typical Saih Rawl field multilateral well design has 5 producing legs supported by a 4-leg water injector. The average length per leg is 2,000 m with a separation of 150 m between the legs. To date more than 20 multilateral wells have been drilled in the Saih Rawl field. The build up section of this well was drilled with a 12°/30 m dogleg. The "mother bore" was drilled in 8 ½ -in. hole and lined with a 7-in. liner. Four windows were cut and the 6 ⅛-in. lateral legs were then drilled to the planned TDs.

This well took 44 days to complete 10,033 m. This represents a daily progress of 228 m/day. Compare this to the 100 m/day progress made on Saih Rawl 23, our first horizontal well, and the progress made in directional drilling technology over the last 8 years is amply illustrated.

Short-radius technology is employed for the re-entry of existing vertical wells and to prevent having to kick off the well in problem zones. In 1998, 7 short-radius wells were drilled for PDO. The build rate for these wells ranged between 30°/30 m and 55°/30 m. (We define short-radius wells as those with a build up rate higher than 25°/30 m).

The Nimr 75 was the first short-radius multilateral drilled for PDO. Both legs were kicked off from vertical, exiting the 9 ⅝-in. casing 23 m apart. The build up

and horizontal sections were drilled in 1 run. The total length of both horizontal legs was 780 m. The well was drilled to a total depth of 1,001 m in 5 days, which represents a daily drilling progress of more than 200 m/day.

3 ¾-in. slim-hole wells were also drilled in Oman to reduce cost and to enable sidetracking from an existing 4 ½-in. liner. Fahud North 258 was the first slim hole multilateral drilled by PDO in January 1998. The 6 ⅛-in. build up section was drilled with a build up rate of 18°/30 m. A 4 ½-in. liner was set in the reservoir and a window exit was planned 20 m above the reservoir in the build up section. The 3 ¾-in. legs 1 and 2 were drilled to a total depth of 1,316 m and 1,194 m respectively. The horizontal legs were turned with 11°/30 m of turn rate inside the reservoir to achieve 150 m of separation between the 2 branches.

COLLISION RISK ANALYSIS

One challenging aspect of complex well design is collision risk analysis. The Yibal, Saih Rawl and Nimr fields have become very crowded. Over 400 wells have been drilled in each of the Nimr and Yibal fields. Currently planning a well in these fields involves collision risk analysis of 5 or more surrounding wells. These wells were drilled as close as 5 m to each other.

DOWNHOLE MOTORS

The earliest downhole motors used to drill horizontal wells in Oman were equipped with bent subs. These motors required trips to change the bent sub in order to adjust build up rates and could not cope with changes in well design that occurred while drilling the well.

These motors were replaced by the Mach 1C AKO (Adjustable Kick Off motor). This is a steerable system able to rotate/slide up to a maximum build up rate of 8°/30 m.

The Mach 1X Ultra Series motors were introduced in 1996 and replaced the Mach 1C. The Mach 1X is a more powerful motor with higher torque and is equipped with a titanium flex shaft. The standard Mach 1X was further modified for Oman operations to enable the motors to rotate through 15°/30 m build ups in 8 ½-in. hole and 12°/30 m in 12 ¼-in. hole.

The introduction of these modified "high dogleg" Mach 1X motors enabled wells to be kicked off deeper enabling pumps to be set deeper and to land the well earlier in the reservoir enabling improved production and expose more reservoir.

To achieve the build up rates necessary for short- and intermediate-radius wells M1CXI titanium motors were introduced in 1998. These motors are capable of achieving build up rates of up to 70°/30 m. This enables us to drill from vertical to horizontal in 25 m of TVD.

MWD technology has developed in concert with the advances in downhole motor technology. The changes in well design and use of more aggressive motors called for a change from simple directional/gamma collar based tools to probe based tools able to cope with the higher doglegs being drilled and be able to operate in slim hole conditions.

The use of formation evaluation MWD has increased considerably in recent years. Multi-propagation resistivity (MPR) technology is used to geosteer horizontal wells to ensure that lateral sections are placed optimally within the reservoir. This reduces well tortuosity to

less than 1 m of TVD. It also reduces cost by replacing wireline logging runs on many development wells.

COILED TUBING DRILLING

Baker Hughes introduced the first coiled-tubing drilling rig to Oman in February 1999. The coiled-tubing drilling rig, Galileo 3, is a fully automated rig with the ability to deploy drilling and work coil strings as well as handle pipe via a conventional mast. The rig is specifically designed for desert drilling and uses parabolic loop technology to deploy the coil string and a fully computerized drilling control system. The Galileo 3 rig is equipped with a full underbalanced drilling package.

To date, 7 horizontal wells have been drilled with Galileo, 3 in the Yibal field, 2 overbalanced and 5 underbalanced. On 3 of these wells a horizontal casing exit was performed.

The BHA deployed by the coil is state of the art "Orient Xpress" BHA. The BHA is controlled online by joystick from the driller's cabin on the rig. A continuous data flow, annular pressure, pipe pressure, WOB, temperature, directional gamma and MPR resistivity data is sent to the surface control unit by a single conductor (essential for drilling underbalanced). The rapid data flow from the BHA guarantees continuous control of the wellpath and formation logging data. The coiled tubing MPR resistivity sub is the first of its kind to be deployed worldwide.

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Schlumberger sets CT first in US Gulf of Mexico

SCHLUMBERGER RECENTLY announced that it successfully drilled and completed the first horizontal well in the Gulf of Mexico. Schlumberger worked with **Spirit Energy 76** on the project. The well was designed, drilled and completed by Schlumberger Integrated Project Management.

An exit window was milled through 2 strings of pipe. 1,390 ft of 4¾-in. open hole was drilled, 750 ft of it in excess of 80°. The well was completed by conveying to 8,100 ft on coiled tubing a horizontal completion assembly composed of sand-control screens, inflatable packer for zonal isolation and **Dowell's** Quantum gravel packer open-hole isolation assembly. The assembly was run and set in one trip, including cement inflation of the packer. This is the first Gulf of Mexico well in which this completion has been run on coiled tubing. The well of interest was 45 years old, according to Schlumberger.

Drilling tools included the Viper coiled-tubing bottomhole assembly, SlimAccess, CoilCAT software and Dowell CT services. ■

Editor's note: *Wellsite technology has always comprised the leading edge of* **DRILLING CONTRACTOR'S** *editorial program. In celebration of the creation of IADC's Drilling Services Division, Drilling Contractor will enhance its coverage of wellsite tech through a new department called "Drilling Services". Drilling Services will provide nuggets of technical news and the wellsite achievements reported by IADC members. These are the types of technical milestones that are breaking new ground for our industry around the world. We hope you enjoy it.*

Maersk, Sperry-Sun set records for horizontal ops

SPERRY-SUN AND Maersk Olie og Gas recently set 4 world records for directional drilling on well MFF-19C in the Dan Field, Sperry-Sun's parent **Halliburton Energy Services** announced. 1 of the records was for muds of any type and 3 were for water-base muds. The records were:

- Longest horizontal section (any mud type): 20,069 ft;
- Longest horizontal section (water-base mud): 20,069 ft;
- Deepest well (water-base mud): 29,631 ft;
- Longest horizontal displacement (water-base mud): 23,265 ft.

Sperry-Sun's Sperry Drill mud motors and AGS (adjustable-gauge stabilizer) tool were used on the well. The wellpath remained consistently in the payzone, according to the service company's announcement. ■