Optimal well placement improves heavy oil production

In Colombia’s Girasol field, bed boundary mapping enables operators to accurately position horizontal wells on the first attempt, avoiding the need for sidetracks and reducing overall development costs.

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Compared to vertical or low-inclination wells, horizontal wells can deliver higher production rates, higher recovery factors, and more efficient use of steam in thermally enhanced recovery projects for heavy oil. However, the shallow, thin, and friable sand reservoirs in Colombia’s Girasol field present several challenges to the accurate placement of horizontal wells.

Schlumberger was contracted to drill a minimum of 25 horizontal wells in the field. The work is being coordinated by the company’s Integrated Project Management (IPM) business segment and involves a range of services including drilling and measurements, geosciences consulting, and completions. Deep azimuthal electromagnetic resistivity logging-while-drilling (LWD) measurements are being used to map bed boundaries in real time, enabling optimal placement of wells despite the presence of unexpected variations in reservoir geometry and lithology. Combined with continuous inclination measurement near the bit and an effective geosteering process, the technology is delivering more than 96.5% average net pay and is minimizing the risk of unplanned sidetracks. Initial data indicate that the new horizontal wells are delivering a seven-fold improvement in production rates compared to low inclination wells in neighboring fields.

Girasol field
Girasol lies in the Middle Magdalena Valley basin. One of the largest heavy oil fields in Columbia, it is operated by Mansarovar Energy Colombia Ltd., a joint venture of Sinopec and ONGC, in an equally shared association with Ecopetrol, Colombia’s national oil company.

The field is composed of a shallow sequence of sediments of fluvial origin, in which sandstone channels contain heavy oil with gravity ranging from 11 to 13° API. The main targets are five stacked, unconsolidated sand reservoirs, ranging in thickness from 10 to 30 ft (3 to 9 m).

Thermal recovery
Nearby heavy oil fields with similar characteristics are being produced using cyclic steam stimulation (CSS or “huff and puff”) thermal recovery techniques applied in vertical or deviated wells. CSS uses the same wells for both steam injection and production. First, steam is injected for a period of time — typically several weeks — to heat the reservoir and reduce oil viscosity. Flow is then reversed to produce heavy oil through the same well. This role-switching continues cyclically over the economic life of the production system.

Average well inclination in the neighboring Jazmin heavy oil field is 30°. These low-inclination wells are relatively low cost to drill; however, they
typically deliver only about 40 b/d with primary (cold) production and 100 b/d after steam injection. Horizontal wells can deliver significantly higher production rates. In addition, horizontal wells have higher overall recovery factors, more efficient distribution of heat throughout the reservoir, and more efficient drainage, particularly in thin formations. Properly placed horizontal wells can represent better value, despite higher up-front well construction costs.

Well placement challenges
Modeling studies in fields similar to Girasol indicate that maximum oil production is achieved when horizontal wells are placed near the bottom of the reservoir. In addition, cumulative steam-to-oil ratio is lowest when wells are near the bottom of the reservoir, meaning that the least volume of steam will need to be generated to produce a particular volume of oil. The objective in Girasol was to place the wells 10 ft (3.3 m) above the bottom shale in each of the reservoir formations.

The geological model for the initial field development plan was based on limited seismic data and some offset appraisal wells. Data from these wells indicated the probable presence of subsurface geological discontinuities such as small faults, lateral or vertical facies changes, and shale layers. Conventional geosteering techniques generally fail to identify such unexpected changes in the reservoir in time to take corrective action. A more proactive approach was required based on real-time LWD measurements and software that would enable in-time drilling decisions to optimize the positioning of horizontal wells in the thin sand reservoirs.

A proactive geosteering service
The bottomhole assembly (BHA) included a deep azimuthal electromagnetic resistivity LWD system — the PeriScope bed boundary mapper. The tool makes 360° deep directional measurements that show the orientation of formation boundaries as far as 21 ft (6.4 m) from the borehole, using a combination of tilted coil technology and multiple frequencies and spacings.

During drilling operations, LWD measurements were transmitted in real time to the surface. Combined with specialized software and processes, these unique, symmetrized directional measurements, with maximum sensitivity to formation or fluid boundaries, make it possible to map boundaries in real time, independent of anisotropy and dip.

During drilling of the horizontal sections, Schlumberger well placement engineers and directional drillers worked together with Mansarovar geoscientists and reservoir and drilling engineers to make proactive decisions to optimize well placement. Web-based collaboration tools were provided that enabled multidisciplinary team members in different locations to visualize the geosteering, modeling, and interpretation results and interact to support field operations.

Well construction challenges
The project requires the drilling of a series of laterally parallel horizontal wells spaced approximately 490 ft (150 m) apart across the field. It is important to maintain lateral separation to minimize interference between wells and optimize draining of the whole reservoir. Each well location has up to three horizontal wells at different depths, placed vertically to drain a single target reservoir. The reservoirs are located 1,100 to 1,500 ft (340 to 460 m) total vertical depth below surface, and each of the horizontal well sections has a lateral extension (measured depth or MD) of 1,200 to 2,350 ft (370 to 720 m).

Because of their shallow depth, placing horizontal wells in the Girasol reservoirs requires very aggressive directional trajectories through soft sand formations. Building from 0° to 90° with a 12 1/4-in. bit required doglegs ranging from 5 to 8°/100 ft (30.5 m). Precise well trajectory planning and BHA designs were crucial to reaching the targets and allowing space for corrections based on the real-time LWD data.

Well casing can sink in soft sand and lose inclination. To reduce this risk, the wells are usually landed by placing the casing shoe within shale 1 to 2 ft
(0.3 to 0.6 m) above the top of the sand reservoirs. In general, the formations dip 2 to 3° in a direction opposite to that of the well trajectory direction, making it even more essential to achieve accurate positioning when landing to avoid reservoir exits in the next phase of drilling.

Positioning accuracy also was an important factor for survey management and anti-collision analysis during the drilling campaign. The field development strategy provides for nine horizontal wells per pad: nominally three wells — one above another — at three different locations. This makes accurate positioning essential at the start of drilling to avoid collision between well bores.

**Drilling pilot project**

To appraise the technologies and challenges of well construction in Girasol, Schlumberger IPM managed the drilling of a pilot horizontal well and a multilateral fishbone well. The services, performed in 2008, used the bed boundary mapping technology to guide proactive geosteering of a PowerDrive X5 rotary steerable system. Total length of the resulting horizontal well section was 1,690 ft (515 m) — 90 ft (27.4 m) more than originally planned — and it was placed entirely within a target that was only about 18 ft (5.5 m) thick, with no reservoir exit, and rates of penetration (ROPs) up to 1,100 ft/hr (335 m/hr).

The second pilot well had a main bore and four legs. The well was geosteered using the bed boundary mapper and the PowerPak motor drilling system. The well achieved 100% net pay in the main bore. More than 4,000 ft (1,220 m) was drilled in one run.

**Horizontal drilling campaign**

The benefits obtained from the bed boundary mapper during the pilot project made this service a baseline for the subsequent drilling campaign, in which Mansarovar chose to use PowerPak motors for steering in the lateral section. The BHA included a tool that provided continuous inclination measurements, both in open hole and inside casing, helping to reduce bit positioning uncertainties and improve the accuracy of casing shoe placement.

Schlumberger placed 16 horizontal wells in Girasol during 2009 and expects to place at least another eight in 2010. The bed boundary mapper has enabled accurate real-time geosteering at ROPs as high as 1,100 ft/hr. Some wells have been extended up to 200 ft (60 m) based on evidence from the new LWD data that the bit was still within productive reservoir formation.

Over the course of the campaign to date, IPM planning and execution practices have led to an average 40% reduction in operating time, a 20% saving in cost, and a net-to-gross-pay zone ratio of more than 96.5%.

Oil production performance from the horizontal wells depends on factors such as lateral section length, properties of the sand lobe drained, and the position of the well within the formation. Initial data indicate horizontal wells in Girasol are producing approximately 100 b/d with primary (cold) production, and about 700 b/d after steam injection, compared with 40 b/d and 100 b/d, respectively, from low-inclination wells in neighboring fields.

**Getting it right first time**

To date, the capabilities of the PeriScope service have mostly been associated with advanced directional drilling systems and high-cost drilling environments. However, it has been shown to add value in a wide variety of projects. Investment in real-time bed boundary mapping can be quickly repaid through better recovery and increased production achieved by more accurately positioning the well bore in the pay zone. Substantial savings also can be achieved by avoiding the need to run sidetracks. In addition to shallow wells for thermal recovery of heavy oil wells, the PeriScope service has been used in diverse drilling projects onshore US, China, and for coalbed methane applications in Canada.

Accurate measurements of bed boundaries not only enable better well positioning, but also can be used to improve the accuracy of geological models, benefitting field development over the long term.