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Improved Hydrocarbon Recovery from Carbonate Reservoir of Mumbai High North Field by Geological Steering Based on Real Time LWD (Logging While Drilling) Data- A Case Study.

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Summary

ONGC has been producing oil from horizontal wells in L-II reservoir of Mumbai High offshore field since 1985-86. Many new wells and side track wells were drilled and completed as horizontal wells and multi-laterals. Drilling horizontal wells in thin layers of carbonate reservoir is a challenge. Horizontal drilling is effective only if the well path trajectory can be accurately steered relative to the “sweet zone” of the target layer. Steering is required because of the unpredictability associated with the lateral structural and stratigraphic changes in the sub-surface within the field. This can be achieved with the help of real time, near bit LWD (Logging While Drilling) measurements and 24 X 7 monitoring by experts to keep the well bore with in the best part of the reservoir. The results are maximum meterage in the pay zone, improved production index and lower completion costs.

In the present case study, a horizontal well was planned in sub-layer ‘c’ of L-IIB reservoir in Mumbai High North field by side tracking from the existing well in the direction N 115° with a horizontal drift of 750m at L-IIB top. However, during drilling, L-IIB top was encountered 6m shallower than prognosis and the required well bore deviation of 90° could not be built up at the landing point which was essential for drilling the horizontal section. Hence, the well was further drilled to land at a deeper layer (L-IIB-d) and 7” liner was lowered. While lowering 7” liner, it got stuck in middle of L-IIB-c layer and the liner could not be released. The hole was cemented at the stuck-up depth and planned for sidetrack using LWD(Logging While Drilling) technology. The well was successfully completed in two laterals in good reservoir facies in spite of unforeseen complications, with the help of real time data analysis. **The well on testing produced oil at the rate of 1800 bopd without any water cut.**

Introduction

The Mumbai High field is located 160 km W-NW offshore from Mumbai in western coastal shelf of India at a water depth of 75 m. It contributes about 70% of India’s total oil production. The field was discovered in 1974 by ONGC and put on production in 1976. The field is divided into Mumbai High North and Mumbai High South by a narrow east-west graben. L-II is the second biggest reservoir (after L-III limestone sequence) and is hydrocarbon bearing only in Mumbai High North. It has passed the mature stage of its producing life and has entered in to the declining phase. Presently, L-II reservoir is passing through a

critical stage that needs special attention for reviving and arresting decline in production. To enhance oil production, many new wells and multi-laterals were drilled and completed as horizontal wells and multi-laterals. In the present case, the well X was side tracked into a relatively new area in the eastern most part of the field and was completed as a multi-lateral in L-IIB-d layer. A suite of advanced LWD services were used to drill these laterals due to their added advantages.

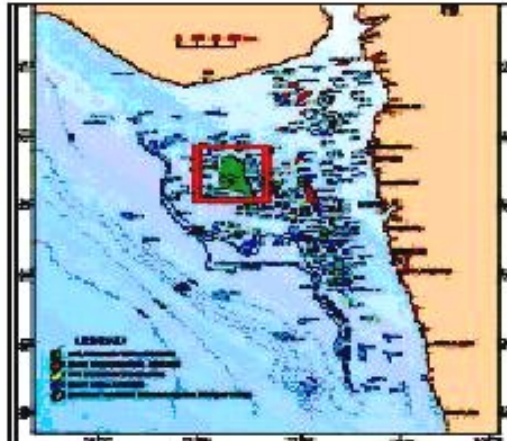


Fig.1 Location map of Mumbai High field

Firstly, as the well was planned to sidetrack to an unknown area having few offset wells, there was a need to evaluate the hydrocarbon potential of the target layer (in real time), in which the drain hole was to be placed. Secondly, the sidetracked location was close to the eastern most fault of the field, and this may result in structural and stratigraphic variations along the well path trajectory in this area. Both these problems can be addressed to by using real time LWD (Logging While Drilling) services, which provide the oil industry with high value, simultaneous real time drilling and logging measurements to find and produce oil and gas efficiently. The real time logging and inclination data helped to interactively adjust the well path trajectory and to place the well in the “sweet zone” of the reservoir.

Methodology

Initial idea about the reservoir structure and property is conceived from surface seismic and offset well log data. However, geological maps are not as precise due to inability to detect subtle features such as small changes in formation dip, lateral facies variation and small displacement faults. Geological placement, as opposed to geometrical placement, is needed due to uncertainties in the continuity of the reservoir facies along the well path trajectory.

Geosteering

Geosteering is the interactive geological placement of the well trajectory along the desired target zone (the most porous and permeable part of the target layer). The established approach to remain with in the sweet part of the reservoir is to geologically steer the well path using real time LWD measurements; ideally by updating, in real time, the pre-job structural and property model of the reservoir. This map is prepared

through detailed modelling of logging data. The directional capabilities of measurements, along with the real time data acquisition, and subsequently analysis of the acquired data help to account for these structural and stratigraphic variations.

Geosteering service consists of pre-job modelling; followed by monitoring and analyzing real time LWD data to geologically steer the well along the desired target. Different LWD tools and hardware/software are used to facilitate the geosteering process.

LWD and Direction drilling services

VISION* services provide drilling and survey data, besides formation evaluation suite of measurements. They are available in various collar sizes like – 4 ¾”, 6 ¾”, 8” to suit various hole sizes in which they are used for logging.

Azimuthal Density Neutron (ADN*) tool provides bulk density – neutron porosity – photo electric factor (Pef) – tool-standoff. Azimuthal data from this tool helps in quantitative evaluation of the formation heterogeneity in terms of properties like - porosity, density etc. This aids in understanding the complexities of the reservoir properties. Real time bulk density and Pef images provide invaluable information about the disposition of the well trajectory with respect to bedding planes / faults etc. Dips picked on these real time images give a structural image of the reservoir section being drilled. Well trajectory can then be effectively steered through the “sweet zone” of the reservoir.

The arcVISION* (Array Resistivity Compensated) technology provides both phase and attenuation resistivities with multiple depth of investigation (DOI); made possible by multiple transmitter-receiver spacing and frequency of measurements. Multiple DOI is critical to identify and differentiate between various environmental and formation effects on EM propagation resistivity measurements, like – washouts, eccentricity, shoulder bed effect, anisotropy and invasion. All ARC* tools, except, the 4 ¾” tool (arcVISION475), has 2MHz and 400kHz frequency of measurement for electromagnetic (EM) propagation resistivity. arcVISION475 uses only 2MHz. All ARC* tools provide total gamma ray data.

Azimuthal Density Neutron (ADN*) tool and IMPulse* (well deviation survey + arcVISION475) tool were used for this job. Positive displacement mud motor was used for directional drilling. The information provided by VISION* services is of vital importance in taking crucial real time decisions like – steering well trajectory, termination of drilling etc. that in turn, saves valuable rig time and enables efficient well completion.

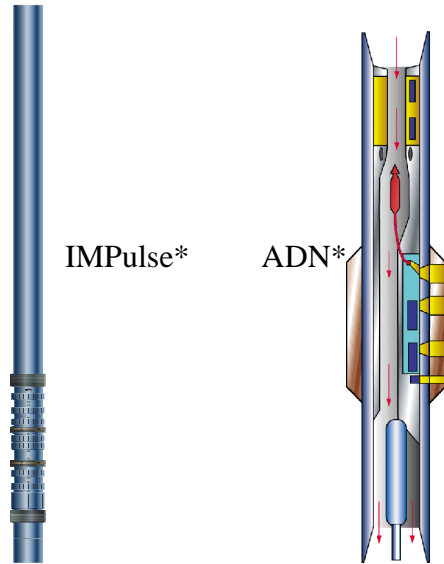
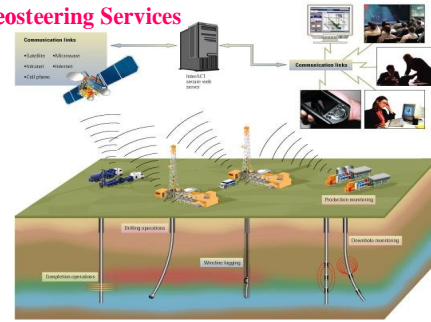


Fig.2 ADN and IMPulse tools providing density-neutron porosity-pef and electromagnetic propagation resistivity-gamma ray-wellbore deviation survey measurements, respectively, in both real time/while drilling mode and recorded mode.

While drilling, down hole data was transmitted in real time from the rig over a secured network-based real time data delivery and monitoring system (InterACT*) to the office base. This enabled the 24-hour real time monitoring operations both at rig and in office by a specialized team of professionals from geology, geophysics, drilling and petrophysics disciplines.

Geosteering Services



- LWD Measurement (GR, Resistivity, Density, Neutron)
- InterACT (Remote Data Streaming System)
- RTGS (Real Time Geosteering)
- WellEye (Image Interpretation)

Fig. 3 InterACT is a means for clients and service provider to collaboratively monitor data and exchange information, solutions and answers (any where, any time, any place).

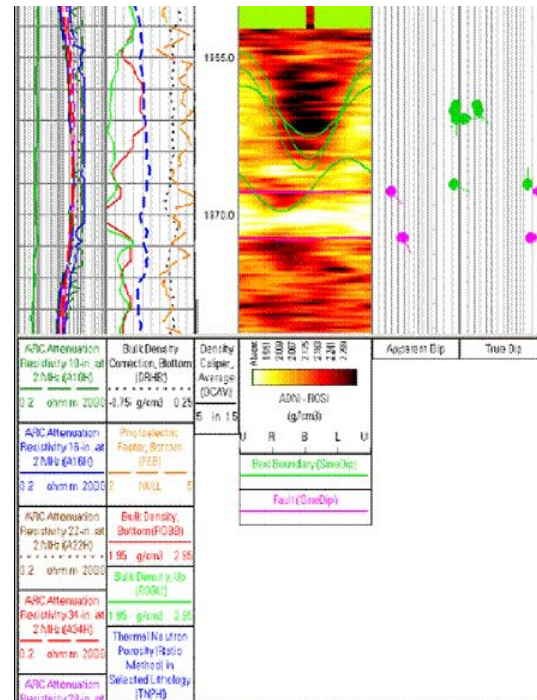


Fig.4 Bulk density recorded mode image showing possible fault encountered around 1970m. Dip of the fault zone shown by pink dots. The true dip of the fault planes is around 80deg. The green dots show the bedding orientation. Bedding is sub-horizontal.

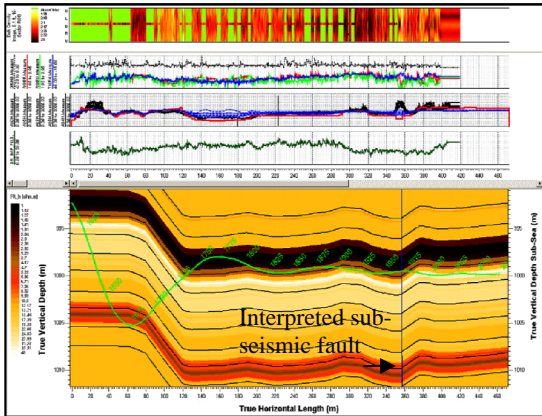


Fig.5 RTGS earth structure and property model for X-zH-Lat2. The green line indicates the actual well trajectory. Resistivity colour scheme is used to indicate layers of different resistivity with in the model; darker colour being conductive. TVDSS is along Y-axis and horizontal length along X-axis.

Real time Geosteering (RTGS*) software prepares a probable geological model of the litho-column to be drilled using a planned well trajectory and resistivity, gamma ray, density and neutron logging data from offset wells prior to drilling. During the drilling process, the modeled data is compared with the real time data to identify formation properties/structure and then make critical steering decisions.

IDEAL* (Integrated Drilling Evaluation And Logging) surface system includes the surface acquisition unit for LWD services.

Case study – Well “X”

Reservoir frame work

The LII reservoir in the Northern sector of Mumbai High Field is the second largest oil reservoir after the LIII limestone sequence in Mumbai High. It is mainly developed in the eastern part of Mumbai High North, which is having a gas cap in the crestal part and water table in the down flank. LII-B is the main producing reservoir which is further divided into six sub-layers namely LII_B_a, b, c, d, e and f starting from the top. Each of these litho-units is separated by fine shale bands ranging between 0.5m to 2 m. in thickness.

The L-II facies are characterized as cyclic deposits indicating frequent sea level fluctuations. The oil bearing zones are restricted only in the Mumbai High North and the southern part is devoid of hydrocarbon. Oil is mainly accumulated beneath the gas cap at the crystal part of the structure. This area is relatively flat and covers an area of 20sq.km. Reservoir thickness is about 36m, divided in to 24m oil and 12m of gas.

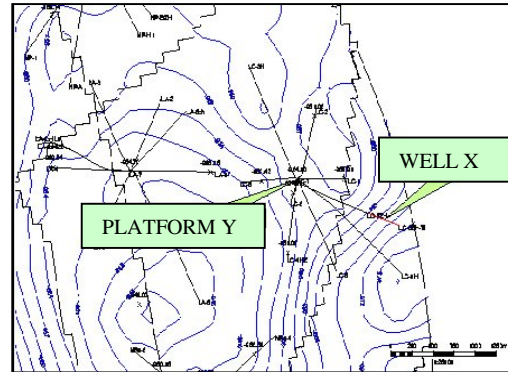


Fig 6 Structure contour map at top of L-IIB-d sub-layer.

Field performance

Commercial production from LII reservoir commenced from June 1985 through well X-5SS. The initial production stood at 780 BOPD. After adding many platforms and wells, production improved many fold and peaked at 40332 BOPD in June 1995, which gradually declined to about 11500 BOPD with increase in W/C to 75% in the year 2004.

The oil production from L-II reservoir remained stagnant between 11,000 – 12,000 bopd for past few years and has posed challenge in terms of reversing its declining trend. After careful analysis of geological, geophysical and petrophysical data, it was observed that, many wells in L-II reservoir were completed in lower layers as horizontal wells. In some cases, the sweet zones were missed out due to lateral heterogeneity exposing bad to moderate facies during drilling of these horizontal wells. The upper layers in these wells have good hydrocarbon potential and remained un-drained. Accordingly, a number of work over and side track jobs were identified and executed by using break through technologies (LWD: Logging While Drilling & SRDH: Short Radius Drain Hole) and this enhanced the productivity from around 11,500 (in 2005-06) bopd to 15,700 bopd (2006-07).

At present there are 40 wells completed in LII reservoir and cumulatively producing at an average rate of about 15500 bopd of oil with an average water cut of 75% and GOR of about 350 V/V. The average oil rate per string is about 300 bopd. Action plan has already been taken for voidage compensation and presently, the VRR(Voidage Replacement Ratio) is around 110%.



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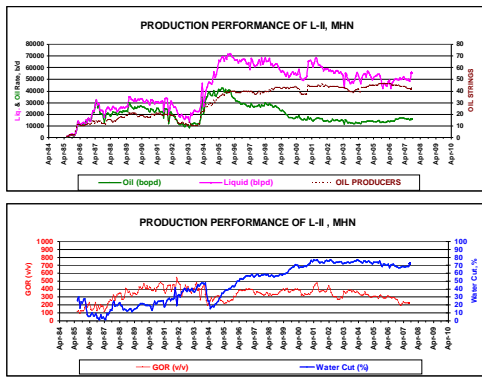


Fig 7 Production performance of L-II reservoir. The pink and green curves show the average liquid production of 50,000 – 60,000 blpd and oil production of 15,500 bopd through around 40 oil strings. The blue and red curves below show average water cut of 75% and GOR of 350 v/v.

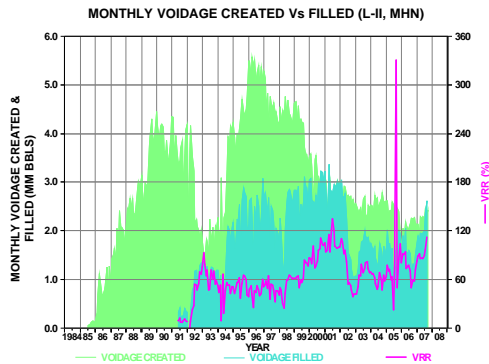


Fig8 Monthly voidage created and filled of L-II reservoir. The green shade indicates voidage created, blue shade shows voidage compensated and the pink curve gives the VRR (Voidage Replacement Ratio), which is presently almost 110%.

Performance of well "X" before side track

The well "X" was completed in c, d, e layers of L-IIB reservoir and put on production in December 1994. The well produced around 400 bopd of oil with high GOR and little water. In July 1997 a squeeze job was done and the layers c, d, e were additionally perforated. The production improved to 1000 blpd with high water cut (60% to 98%). The GOR again increased to more than 2000 v/v gradually. Production logs were recorded which indicated mainly gas with small amount of oil from all the layers. The GOC in this well is at 941m TVDMSL and high GOR could be due to proximity of perforated zone to GOC.

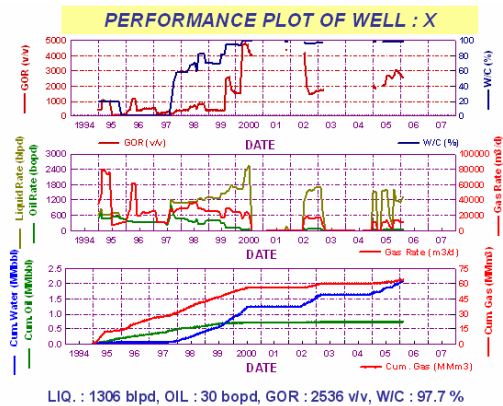


Fig.9 Performance Graph of Well "X" prior to sidetrack (ST).

The well ceased to flow in Jan'06 due to high water cut (98%). The well has cumulatively produced 0.0973 MMt. of oil.

Side tracking of well "X" as well "XzH"

In view of the current poor performance, the well was sidetracked as X-zH to the new location in the direction N115.5° with horizontal drift 750m at L-IIB top, from the platform. Detailed reservoir analysis of the area indicated good oil potential in sub-layer L-II B-c, which is relatively un-drained. Hence the well was sidetracked as X-zH in the drift and direction mentioned above.

The well was initially planned to complete as a horizontal drain hole in L-IIB-c layer. While drilling it was observed that L-IIB top structurally came 6 meters higher in TVD than expected and an angle of 90 degrees could not be built up at the planned landing point. So, drilling was terminated at a depth of 1541m MD, where the angle was only 82 degrees. It was decided to drill further up to L-IIB-d top. Accordingly, the well was drilled further up to the landing point.

While lowering 7" liner, the liner got stuck at 1606m MD, which was found to be in the middle of L-IIB-c layer. The stuck up could not be released and it was decided to cement the hole at 1606m MD by lowering 7" liner with shoe at 1606m MD.



Drilling of Lateral-1

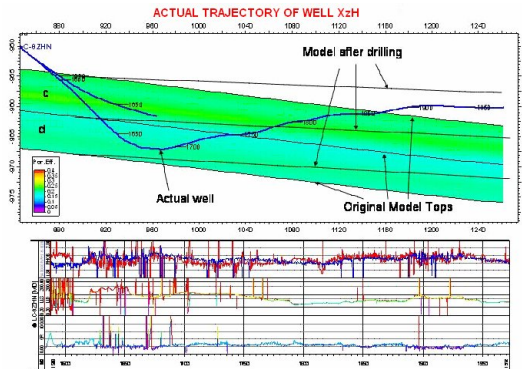


Fig.10 The Upper portion shows the Actual Trajectory of Lat-1 (blue curve) and the Lower Portion depicts the Log motif measured by LWD VISION* services.

The 6" horizontal hole (LAT-1) was drilled by using Schlumberger LWD tools in the interval 1606m MD to 2031m MD. The open hole log analysis indicated development of very good facies in the interval 1620m MD to 1650m MD, having resistivity in the range of 15ohm.m to 25ohm.m and porosity of around 27%. The facies deteriorated in the interval 1650m MD to 1690m MD, with resistivity of around

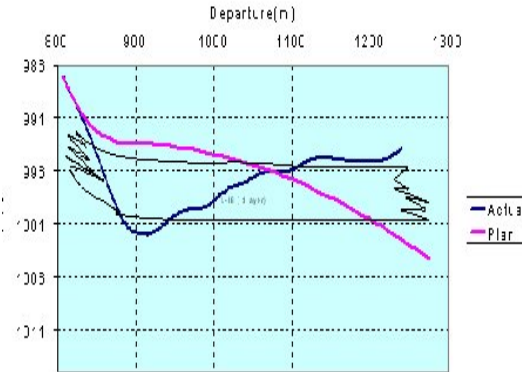


Fig.11 Actual vs planned trajectory in Lat-1

10ohm.m and porosity of 22-24%. Again good reservoir facies observed from 1690m MD and continued up to 1750m MD. The reservoir characteristics deteriorated from 1750m MD onwards till end of the lateral section at 2031m MD.

Drilling Of Lateral-2

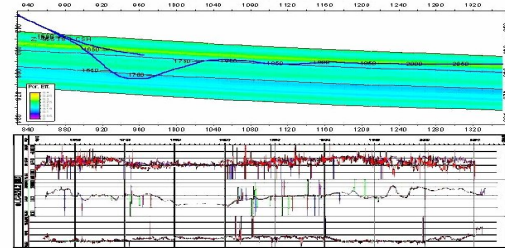


Fig.12 The Upper portion shows the Actual Trajectory of Lat-2 (blue curve) and the Lower Portion depicts the Log motif measured by LWD VISION* services.

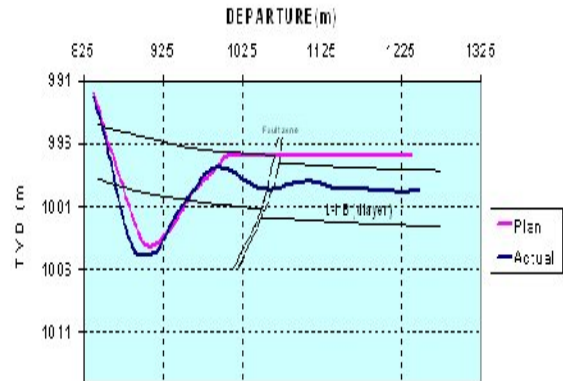


Fig.13 Actual vs planned trajectory in Lat-2

Due to poor reservoir characteristic in major part of the horizontal section, it was decided to drill the 2nd lateral by open hole sidetrack from 1630m MD. The 2nd lateral was drilled in the interval 1630m MD to 2073m MD. Development of very good reservoir facies was observed from 1630m MD to 1730m MD. The facies deteriorated from 1730 m. to 1825 m. Good facies again observed from 1825 m. till bottom of the lateral section. Drilling terminated due to mud loss.

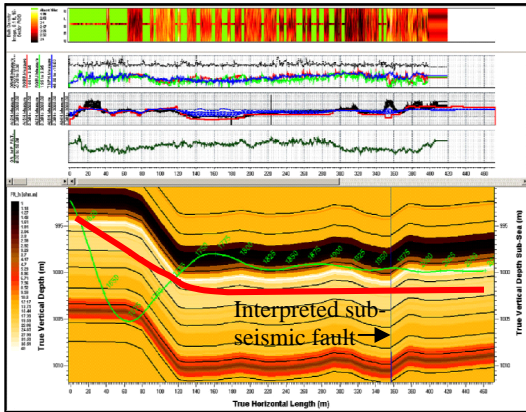


Fig.14 RTGS earth structural and property model for Lat2; prepared post-job with recorded mode LWD data. The green line indicates the drilled trajectory and the red line highlights the ideal geosteered trajectory that could have been drilled if a real time 24-hour modelling activity was done, besides monitoring the real time LWD data. The “ideal trajectory” in red has much less dogleg severity and higher reservoir exposure along its length; a favorable situation for higher production and less costly completion.

Performance of the well XzH after side track

The performance of the well, vis-à-vis the platform (L-II Reservoir), improved remarkably after side tracking. The well is producing oil @ 1800 bopd without water cut. Before the sidetrack of well “X”, the average oil rate per well from the platform was 326 bopd per string with average water cut of about 75 %. After the sidetracking of X as X-zH, the performance of the platform (Oct, 06) improved to 590 bopd per string with average water cut of 53 %.

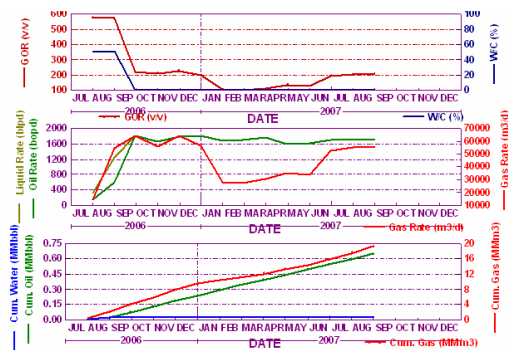


Fig.15 Performance graph of well “XzH”. The top track shows water cut and GOR; the middle track liquid and oil production; the bottom one shows cumulative oil and liquid production. Presently, bldp: 1705; bopd: 1705; GOR: 206 v/v; W/C: Nil.

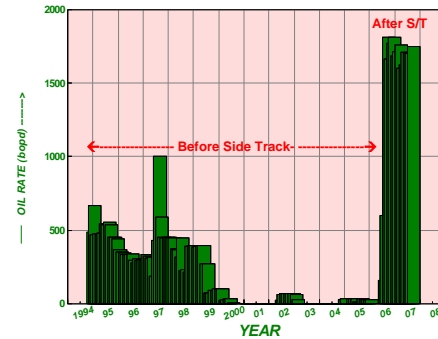


Fig.16 The Well Performance Before and After Side Track

Conclusions

1. A losing situation that arose due to short landing and liner stuck-up was converted into a winning one by using the approach of real time monitoring/analysis of the LWD suite of measurements and the well was successfully completed in two laterals in good reservoir facies in spite of various unforeseen geological and operational complications.
2. Before side tracking, the average oil rate per well from the platform was 326 bopd per string with average water cut of about 75%. After side tracking the well, the performance of the platform improved to 590 bopd per string with average water cut of 53%.

Recommendations

1. Geologically complex situations, in which the target layer’s structure and property is unpredictable, the use of geosteering with LWD measurements and real time modelling is the preferred option to avoid costly and time consuming operational remedies like – drilling and logging a pilot hole, sidetracking etc.
2. A large amount of data is available during drilling. It is important to combine all available data, which can subsequently be analysed for making interactive adjustments to a well path that generally adds significant value to the well.
3. The un-drained area lying near the north-eastern most part of the Mumbai High field has good hydrocarbon potential and hence, ceased / non-producing wells should be suitably re-located to rejuvenate production.



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