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Identifying Target Layer for Horizontal Drainhole Drilling: Role of Straddle Packer Modular Dynamic Tester - A Case Study of Mumbai High South

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Summary

A massive re-development program has been undertaken in Mumbai High, a multilayered complex carbonate reservoir, to increase oil production from the field. Drilling of horizontal and ERD (Extended Reach Drilling) wells is a major feature of this redevelopment program. The target layer for drilling the laterals is decided on the basis of log response and production behavior of the layers in the offset wells. In some cases, this becomes difficult because of ambiguous conventional log response in high angle/horizontal wells. The geometry of the laterals is decided after making a critical analysis of the geological model and also studying the structural configuration.

This paper discusses the case of a well in Mumbai High South, where the target layer for drilling drainhole was firmed up on the basis of Straddle Packer Modular Dynamic Tester (MDT) results. Conventional open hole logs indicated presence of hydrocarbon in the layer in which the lateral was initially planned. However, the layer was found to be mainly flowing water at all the straddle packer stations carried out in that layer.

Based on this observation, target layer for drilling the laterals was changed to a shallower layer where straddle packer tests indicated presence of oil. Subsequently, two laterals were drilled deploying Logging While Drilling (LWD) in the identified target layer. On activation, the well produced 458 bopd with 20% water cut.

Introduction

Brief Description of Mumbai High Field [1,2]

Mumbai High, discovered in 1974, is an offshore oil field at a water depth of about 80m in the Arabian Sea. The field, covering an area of around 1200 sq km, is situated in the western offshore at a distance of nearly 165 km in the west north-west direction from Mumbai city in India. On the basis of an E-W trending shale channel in L-III reservoir the field is divided into two blocks, Mumbai High North (MHN) and Mumbai High South (MHS). Oil and gas has been discovered in a number of reservoirs viz. LI, LII, LIII, LIV, LV, basal clastics and the fractured basement. Out of these, LII and LIII are the two main limestone oil reservoirs of Miocene age. The LIII reservoir is multilayered with shale, limestone sequence and holds about 94% of the total initial oil in place of the field. Bombay High is one of the most complex fields in terms of reservoir heterogeneity. The major reservoir (L-III) is multi-layered with 10 limestone layers designated as A1, A2-I to A2-VII, B & C of 5-10m thick which are separated by 2 to 5m shale. More than 600 development wells, both producers and injectors have been drilled.

Under a redevelopment plan for this field, Infill drilling through available spare slots and side-tracking/re-drilling of the existing wells, drilling of horizontal wells,drainholes and Extended Reach Drilling (ERD) have been taken up to exploit the layer that can give maximum oil production with minimum water cut. About 213 horizontal wells have been drilled under the redevelopment plan. A number of sub-optimal producers were also converted as horizontal sidetracks under brown field development.

Identification of target layer

Identification of target layer and subsequent drilling of drainholes is based on the production, injection, pressure, seismic and petrophysical data of the offset wells. In cases, where there are no offset wells available, 8 ½ inch pilot hole is usually drilled to ascertain the hydrocarbon potential of the various layers and the layer which has maximum hydrocarbon saturation is chosen as the target layer for drilling drainholes. Pilot hole is subsequently cement plugged and a fresh hole is drilled upto the target layer facilitating drilling of 6 inch drainhole.

Log data in the pilot hole needs to be supplemented by testing because of prevailing reservoir conditions in this field like differential depletion, high capillary pressure effects, and presence of injection water along with connate water [3]. Primary objective of testing is not only to confirm the *in situ* fluid in the target layers but also to identify which of the fluids will be mobile under dynamic conditions before a lateral is drilled. Testing can be achieved by using wireline formation tester based on pumpout technique. Pump-out based real-time fluid identification is a viable option for fluid identification and for confirming mobile fluids. This paper describes briefly the application of Straddle Packer module of Modular Dynamic Tester, a wireline formation tester, in testing a target layer for drilling horizontal drainholes in Mumbai High South field.

MDT Theory and Modules [4]

MDT technology is designed around a modular principle, i.e., different functional parts of the formation tester tool are divided into separate and independent modules. Thus, there may be a single probe module, a downhole pumping module, a fluid analyzer module, an inflatable straddle packer module and various types of sampling modules. Tool modularity makes for the flexibility of application because tool can be configured depending on the objectives.

Straddle Packer Module: The straddle packer module, also called the dual packer, has two packer elements that are inflated to isolate a minimum borehole interval of about 1 m [3.3 ft]. The entire borehole wall is open to the formation, so the fluid flow area is 1000 times larger than with conventional probes. Hence, relatively large flowrates can be obtained even in very tight formations, where a normal single probe tester would find the formation permeability to be too low to produce fluids. This module is also very useful in unconsolidated formations since the large flow area ensures that a very small pressure differential is sufficient to make fluids flow from the formation, hence avoiding the excessive pressure differentials that could cause sanding or formation collapse. Low pressure differential also makes it easier to sample formation fluids nearer to the *in situ* pressure condition, thus helping to obtain representative PVT samples.

Optical fluid analyzers: Apart from pumpout module, which pumps fluid from the formation into the mud column, another requirement for formation fluid identification downhole is a detection system to indicate fluid type, which is called the optical fluid analyzer. The flowline passes through two independent optical sensors. In one of the sensors, absorption spectroscopy in the visible and near infrared region is used to detect and analyze liquid and in the gas detector special type of optical reflection measurement detects gas. They are used extensively to identify formation fluids downhole while pumping along with real time continuous measurement of fluid resistivity and temperature. The optical fluid analyzer also calculates important hydrocarbon properties such as GOR (Gas-Oil ratio).

Case Study

An 8 ½ inch pilot hole was drilled in well 'A' of Mumbai High South field to evaluate the hydrocarbon potential of layers A1, A2-I to A2-VII, B, C and D, so as to decide the target layer to drill horizontal drain hole. Different Suites of wireline logs were recorded including PEx-HRLA* and CMR* (Combinable Magnetic Resonance).

ELAN Interpretation

ELAN***** based fluid saturations in the pilot hole indicated that both the layers B and A2-VII have oil saturation varying form 10 to 40%. Therefore, both were probable targets for placing laterals. However, it was also seen that the moved hydrocarbon saturation (due to mud filtrate invasion) in layer A2-VII was significant whereas layer B showed lower or nil moved hydrocarbon saturation. Also non-clay intergranular water saturation (SUWI) was

* Mark of Schlumberger

varying from 60% at the top of layer B to nearly 90% at the bottom of layer B.Whereas layer A2-VII showed lower SUWI saturation, varying from 60 to 80 % . Fig. 1 shows ELAN Fluid saturations for both the layers. In the right most track, yellow is the moved hydrocarbon saturation and green is the oil saturation. The green curve in the third track from left shows SUWI plotted on a reverse scale of 0 to 1.

MDT Summary

ELAN interpretation was confirmed by MDT fluid identification and sampling because, as explained before, it is necessary to identify formation fluids that will flow under *in situ* condition. Therefore, with this background MDT flow tests were conducted in different layers. Initially pumpout attempts were made with single probe, in which fluid identification and sampling was done in layers A2-V, B and C. Table 1 summarizes LFA* and surface sample results of all the pumping stations with single probe. Except at one of the depth stations in layer B (at 1865.03m), pumpout attempts with single-probe in layers B and A2-VII were unsuccessful, due to high drawdown. This also corroborated with the single-probe pretest mobilities, which were low in these layers, as low as 0.2 mD/CP at one of the test depths in layer A2-VII (Table 2), indicating tighter formations thus difficult to pump. It was also seen from CMR based Timur-Coats permeability log (KTIM) that these two layers indeed have lower permeabilities compared to layer C and the one successful point at 1865m in layer B (Fig. 2).Therefore, it was decided to run straddle packer along with other requisite modules and to attempt pump out against these layers. In the subsequent straddle packer run, layers B and A2-VII were successfully characterized. Table 3 summarizes the LFA and surface results of the pumping stations conducted with straddle packer.

Layer / Measured Depth	**Pumping Time & Volume**	**LFA Response**	**Sample Results at Surface**
C, 1905.07m	1 hr, 9.2 liters	Formation water / filtrate	Formation Water / filtrate of salinity 15120 ppm
C, 1890.1m	30 min, 9.2 liters	Water	No Sample
B, 1865.03m	30 min, 4.8 liters	Filtrate	Filtrate of salinity 7065 ppm
A2-V, 1768.5m	1 hr, 21liters	Prominent oil slugs with filtrate	Oil, some gas and filtrate of salinity 8775 ppm

Table 1: Single Probe Results (Mud filtrate Salinity = 7020ppm, Formation Water Salinity = 23000ppm)

Layer	**Measured Depth (m)**	**Mobility (mD/cP)**
C	1905.1	11.2
	1890.1	120.5
B	1865	5.2
	1854	6.8
	1853.1	2.9
	1852	28.2
	1852	11.3
	1847.2	6.6
	1845	3.7
	1844	5.3
	1841.6	1.6
	1839.6	2.2
A2-VII	1817	0.2
	1807	12.4
A2-VI	1787	2.5
A2-V	1768.5	63.2
	1757	2.2
A2-III	1744	0.8
	1747.5	1.9
A2-II	1728	4.1

Table 2: Single Probe Pretest Mobilities in different layers

* Live Fluid Analyzer, Class of Fluid Analyzers

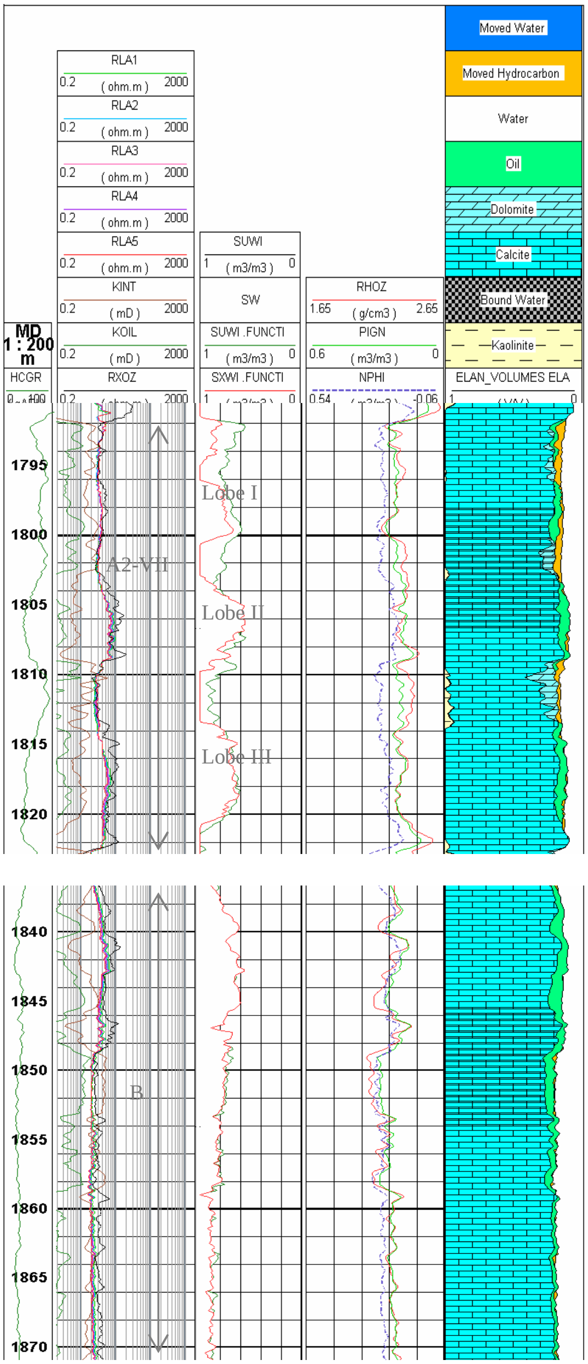

Figure 1: ELAN based fluid saturation for A2-VII and B, showing presence of moved oil saturation (yellow) in A2 -VII and showing absence of any moved oil saturation in B.

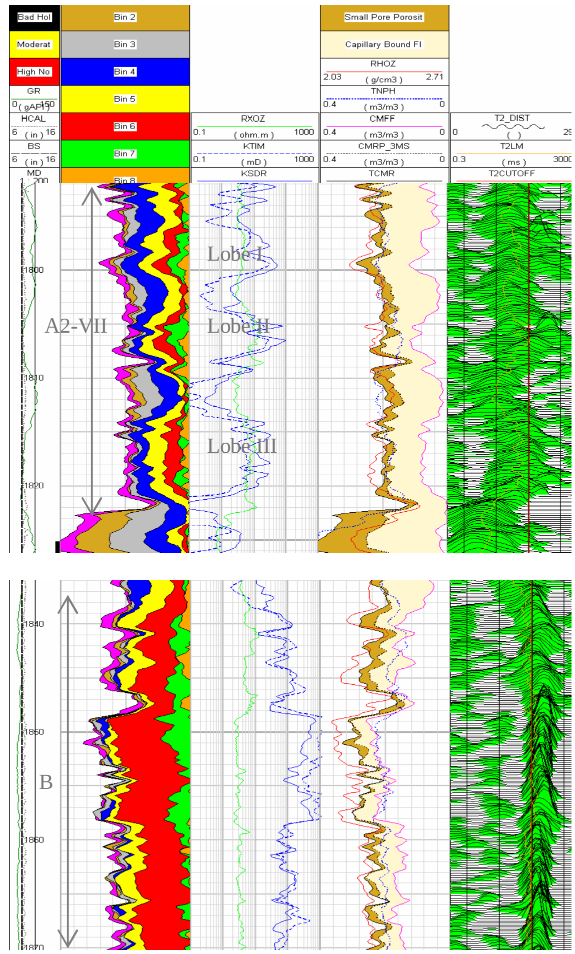

Figure 2: CMR based Permeability log, KTIM, for layers A2-VII and B, showing that permeability in A2-VII is much lower as compared to layer B

Fluids were identified in real time on the basis of LFA.At 1807.5m, in layer A2-VII, an interesting case of fluid identification was observed. Oil slugs started appearing only after 2.5 hours of pumping out filtrate at around 500rpm (Fig.3).Gradually slugs increased in size and in later periods showed some gas along with prominent oil slugs. At 1844m, in layer B, though thin oil slugs started appearing in the LFA log after around 6 hours of pumping but did not increase in size significantly even after 8 hours of pumping (Fig.4).This indicated that layer A2-VII has better characteristics than B in terms of oil production.

Layer / Measured Depth	Pumping Time & Volume	LFA Response	Sample Results at Surface
B, 1852.5m	6.5 hrs, 268 liters	Filtrate with some gas	Filtrate of salinity 7616 ppm and gas
B, 1844m	8 hrs, 220 liters	Thin oil slugs with formation water / filtrate & some gas	Oil, formation water / filtrate of salinity 17573 ppm and some gas
B, 1839.5m	8 hrs, 50 liters	Thin oil slugs with filtrate	Oil, filtrate of salinity 7029 – 7616 ppm and gas
A2-VII, 1819.5m	5.5 hrs, 144 liters	Prominent oil slugs with filtrate	Oil, filtrate of salinity 7616 ppm and gas
A2-VII, 1807.5m	4 hrs, 187 liters	Prominent oil slugs with filtrate	Oil, filtrate of salinity 8200 ppm and gas
A2-VII, 1799.6m	5 hrs, 100 liters	Thin oil slugs with filtrate	Oil, filtrate of salinity 8200 ppm and gas

Table 3: Straddle Packer Results (Mud filtrate Salinity = 7020ppm, Formation Water Salinity = 23000ppm)

Drainhole Drilling

Based on the straddle packer results, A2-VII was identified as the target layer for drilling drain hole. Though, A2-V also showed prominent oil slugs during pumping, but A2-VII was selected as the target layer. A2-V layer may be exploited at later stage. As shown in Figures 1 and 2, layer A2-VII has 3 lobes. Lobe-I, neither showed prominent oil slugs, nor they increased in size during pumping, as shown in Table 3 at depth 1799.5m. Lobes II and III have TVD thicknesses of 2m and 3.5m with sweet zone thicknesses of 1m and 1.5m respectively (Fig.5).Therefore lobe-III of A2-VII, having greater TVD & sweet zone thickness than lobe-II, was a better candidate for placing drainhole. Pilot hole was subsequently cement plugged and two 6" laterals of length 488m and 389m length were drilled deploying LWD technology [5] and completed with a combination of blind / perforated 3- ½ " tubings.

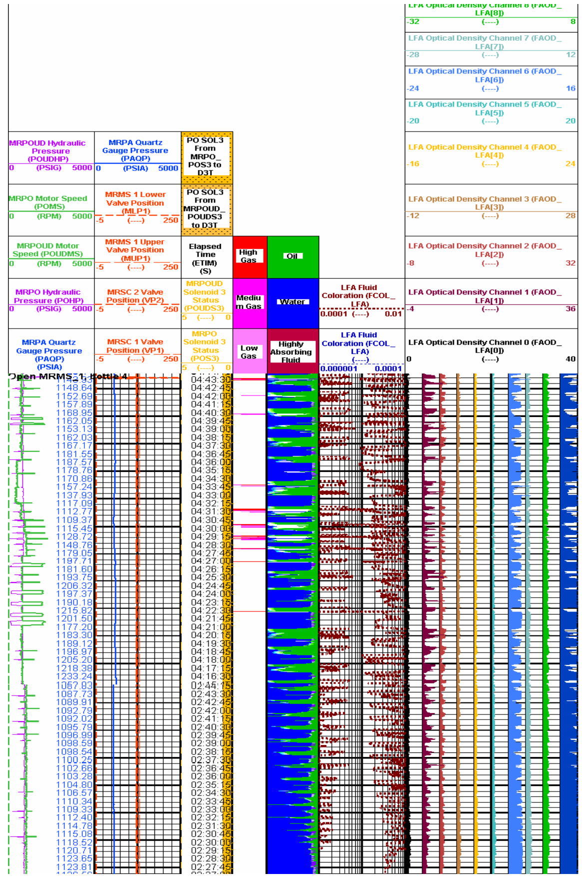

Figure 3: LFA Fluid Identification at for layer A2-VII.Oil slug starts showing up after 2.5 hours of pumping and increases in size

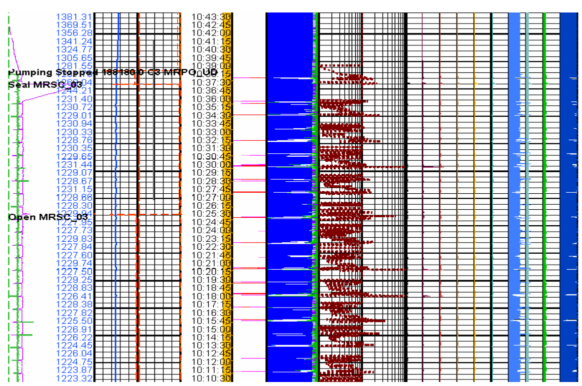

Figure 4: LFA Fluid Identification for layer B. Observed thin oil slugs which did not increase in size even after pumping for 8 hours.

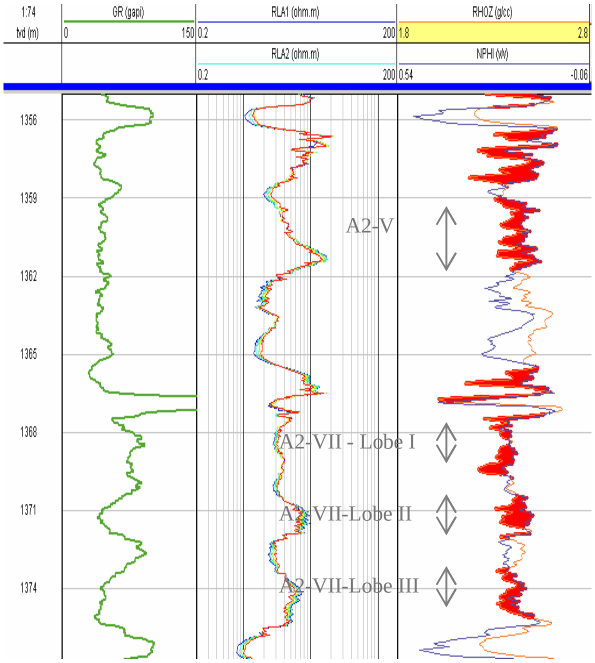

Figure 5: Layer A2- V and the three lobes of A2-VII in TVD log

Production Testing Results

The well on activation produced 458 bopd with 20% water cut and 307 GOR (v/v). Fig. 6 shows performance of the well.

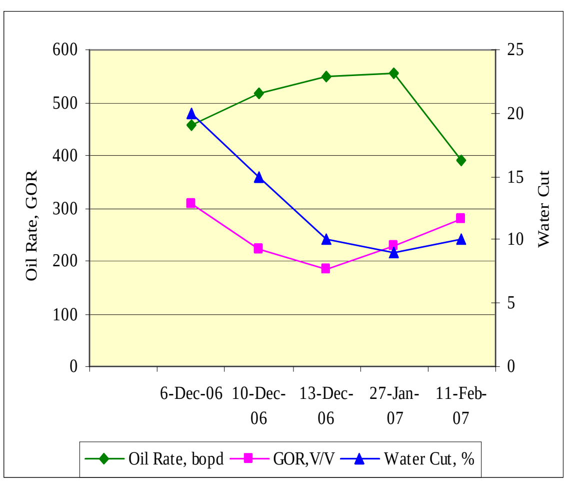

Figure 6: Production Test Performance of Well ‘A’ on 56/64” choke

Conclusions

- Straddle Packer pumping proved critical for fluid identification in a tight layer, where pumping using a single probe was difficult due to excessive drawdown on sandface.
- Straddle Packer along with LFA helped in identifying layer A2-VII as the target layer for drilling drainholes.
- Further, analysis of Straddle Packer fluid identification results along with zone thickness information helped in concluding that out of the 3 lobes in A2-VII, lobe-III is best zone for well placement.
- Subsequently, two laterals were drilled in the lobe-III of A2-VII, which on activation produced 458 bopd with 20% water cut and 307 GOR (v/v).

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