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Innovative concepts in time lapse reservoir characterization leading to incremental oil: A case study in an offshore carbonate reservoir

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Abstract

A matured field is faced with numerous challenges that are detrimental to oil production. Precise diagnosis of the problematic areas result in formulation of remedial measures which can remarkably enhance oil production with substantial reduction in water cut. The paper deals with case studies of revival of underperforming wells through rig less intervention in a matured complex carbonate reservoir with upward shift in oil water contact & characterized by high density of injection water conduits that are making their way through producers and suppressing the oil production potential.

Precise characterization of prevailing reservoir dynamics was the first step towards planning remedial interventions for revival of sick wells. This included the acquisition of the down hole flow profiles, their analysis and remedial actions for reduction in water cut. Apart from this identification of bypassed oil zones not prone to injection water breakthrough on perforation were identified with the help of Pulsed Neutron Logging. A judicious combination of Production Logging & Pulsed Neutron Logging enhanced oil production through reduction in water cut and additional oil through bypassed sub units. Accurately computed oil saturations through processing of open hole logs were compared with oil saturations obtained through Pulsed Neutron Logging in a time lapse of approximately 17 years.

This resulted in demarcation of sub units holding bypassed oil. Sigma log obtained through Pulsed Neutron Logging was converted to salinity log through a transform developed by the authors, which indicated sub units in the reservoir holding injection water. It was observed that bypassed oil sub units fell under two critical categories viz.sub units devoid of injection water & those holding injection water. Bypassed oil sub units devoid of injection water contributed considerable oil on perforation. Data acquisition, data analysis and subsequent remedial actions in the wells intervened have been explained in the paper. With an expenditure of approximately US$ 200000, the authors generated an approximate profit of US$ 3 million in a matter of three months. With sequential interactive presentation slides the authors would explain in detail the methodologies adopted, which would certainly add value to the oil industry knowledge data base. The work has opened new avenues for application to other wells on different platforms. The same methodology with further refinement can bring excellent results in a cost effective way.

Introduction

The main reservoir is Middle Eocene carbonate deposit which is characterized by presence of vugs, dissolution channels, fractures (both vertical and horizontal) and hence high permeability streaks that provide conduits for early water breakthrough. This has been primarily responsible for declining oil production. Average water cut in the field is 80 %.

The offshore platform on this reservoir, on which the rig less operations were carried out posed a special challenge due to its proximity with two water injection platforms. The injection water accumulation in the drainage area covered by the wells of this platform became evident through current temperature anomalies and salinity contrast between the formation water and the accumulated injection water (the relevant computation is explained later in this paper) in the vicinity of the wells taken up for time lapse survey. Thus the challenge was to study the flow dynamics so that additional perforations in the bypassed sections yield water free oil and that very little scope is left for water encroachment even after prolonged production.

The strategy adopted included well diagnostics followed by intervention to increase oil production and

reduce water cut. Production logging was carried out to identify the flow profile. This was followed by Pulsed Neutron Logging to determine hydrocarbon saturation in cased hole environment. Integration of data from production logs and pulsed neutron spectroscopy helped to identify depleted zones and zones of by-passed oil. Through-tubing isolation plugs (wherever applicable) were placed to isolate water-producing intervals. Oil in bypassed zones was tapped by additional perforations. Innovative approach to work out the formation water salinity through pulsed-neutron logging identified zones of injection water breakthrough. Such intervals were avoided while adding new perforations.

With the successful implementation of above techniques, the oil production of the intervened wells increased by 53% from 1773 BOPD to 2708 BOPD. The average water cut of the platform reduced from 80% to 76%.

The objective of the operation was to increase oil production while keeping the water and gas production to a minimum. As there was no rig available, the operations had to be carried out on a Modular Skid Unit (MSU), which constrained the tools and methods available to achieve the desired goals.

The planning for the project started with data analysis, which primarily included investigating the history of the wells. The production history was analyzed to understand the trend of production decline and increase in water cut. Work over history of each well and its impact on the production was also analyzed so as to learn from past practices. Completion details were studied to ascertain the feasibility of wire line logging and intervention.

Old logs were investigated to further aid in finding suitable solutions. The open hole logs were interpreted to determine the original GOC and OWC. Historical production logs were analyzed to infer oil/water/gas producing intervals. Cement evaluation logs were also analyzed to gather information on cement integrity and possibility of hydraulic isolation.
To carry out the aforesaid objectives, following methodology was applied on a case-by-case basis. Production logs were acquired to identify water/hydrocarbon producing zones and also to quantify the production rates. Pulsed Neutron Logging was done wherever deemed necessary and permitted by formation characteristics. Pulsed Neutron Spectroscopic analysis yielded current day oil saturation information. This information was integrated with the information obtained from Production logging to draw inferences on which zone should be perforated to increase oil production and which zones should be shut-off to reduce water production. 2” HSD and/or 2 $^{1}/_{8}$“ Enerjet guns were used for additional perforation/ re-perforation in the recommended zones. Water producing intervals were isolated using through-tubing isolation plugs. The operations and results on each well are summarized

Well-1

This well was completed as a producer. Initially it was producing close to 950 bbls of oil without any water cut. Before operations, the well was producing 245 bbls of oil with 84% water cut.

Production logging revealed that the bottom perforation was contributing only water .Hydrocarbon entry was mainly from the top portion of middle perforation. The upper perforation interval could not be logged because of proximity to the tubing shoe. Subsequent Pulsed Neutron Logging also showed that the bottom zone was depleted whereas the upper zones had substantial hydrocarbon saturation. Saturation logging also pointed at certain zones which had not been depleted at all.

Based on the above observations, it was decided to set a through tubing mechanical plug between the middle and the bottom perforation. This was done to shut-off the water coming from the bottom as indicated by Production log. Consequently, the oil production increased to 445 BPD and water cut reduced to 40%.

Two sets of additional perforation (2m each) were carried out at the zones that showed no depletion in the saturation log. As a result, the oil production further increased to 603 BPD. However water cut also increased to 52%

Well -2

This well was completed with 5 sets of perforation. Right from the outset, it was a low oil producer with high water cut (79 BOPD with 82% water cut). The well was shut-in when the water cut reached 99 %.
Production logs showed that four out of five perforations were producing only water with maximum water being contributed by the third perforation from bottom. A minor cross flow was also observed between the third and fourth perforation from bottom. A little amount of hydrocarbon was being produced from top perforation along with substantial quantity of water.

The cement bond log (logged at the time of initial well completion) showed poor bonding in the zone of interest. Mechanical through tubing bridge plug was set so as to isolate the bottom four perforations. Additional perforations were done above and below the top perforation (3m) with a view to increase the oil production. Oil production did increase but the water production did not reduce. A second production log was done to investigate the reason for this. The production log showed that the Bridge plug was successful in stopping the flow of water inside the casing. But the water was actually channeling from behind the casing and being produced from the top perforation.

Well-3

In this well because of mud loss problems, the open hole logs could not be recorded. The perforations were done on the basis of Cased hole CNL. Initially the well was producing 1025 bopd with 20% WC. The production rates before operation were 342 bopd with 67% water cut.

Production logging revealed that substantial oil was being produced from the bottom perforation also. Therefore, use of Mechanical Plug Back Tool for setting Through Tubing Isolation Plug, was ruled out. Saturation log could not be run because of low porosity (<13 pu) in most of the interval of interest. Based on open hole logs correlation, two sets of perforations were done.

The oil rate increased to 466 bopd and water cut reduced to 54%.

Well -4

Initially the well was producing 1685 bopd with <1% water cut. The current production rates prior to operations were 258 bopd with 89%v water cut.

Production logging indicated that the bottom perforations were producing little amount of water and no hydrocarbon. A squeezed interval was also producing substantial quantity of water. Thus, to shut-off this bottom water, Through-tubing mechanical bridge plug was planned to be set. Unfortunately, the plug could not be set because it got held-up in the tubing. Saturation log was not run because there was no unpenetrated section of pay above the top perforation.

Additional perforation was done to extend the top perforation in order to allow easier entry of oil. The oil production increased to 460 bopd and water cut reduced to 79%.

Well 5

Initial production rates from the well were 2482 bopd with traces (<1%) of water whereas before operation, the well was producing 362 bopd with 88% water cut.

Production logging was carried out without a spinner because the spinner dummy was getting held-up in the tubing due to presence of scales in the tubing. Production log indicated that part of bottom perforation was producing hydrocarbon. Therefore, through-tubing isolation plug was not an option.

Saturation log was acquired to determine the current day oil saturation in the complete interval. The results were quite encouraging and an 11m thick zone was found to be in almost un-depleted condition. Additional perforation was carried out in this zone to tap the remaining hydrocarbons.

Well 6

Initial production rates from the well were 1571 bopd with traces (<1%) of water. Prior to the operation, the well was producing 216 bopd with 81% water cut.

Entire interval right from GOC to OWC was covered through existing perforation, so there was no scope of any additional perforation. Consequently, it was decided to run only a production log to

identify and shut bottom water, if any. Production log showed that bottom three perforations were watered out Through-tubing isolation plug was set so as to isolate the watered out perforations. Consequently, the water cut reduced from 82% to 79% and oil production increased to 386 bopd.

Well 7

Initial production rates from the well were 2152 bopd with 10% water cut. Last test prior to the operation indicated oil production rate of 135 bopd with 93% water cut.

Production logging indicated that most of the production (water and hydrocarbon) was coming from top perforation. A little amount of water was being produced from the bottom perforation. Through Tubing Isolation plug was set in between the two perforations to shut off the bottom water. 2m of perforation was added above the top perforation.

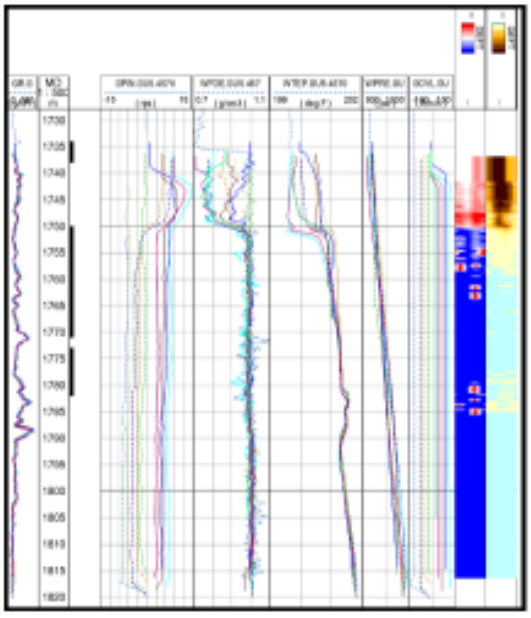
There was no gain in oil production and there was marginal increase in water cut from 93% to 94%.

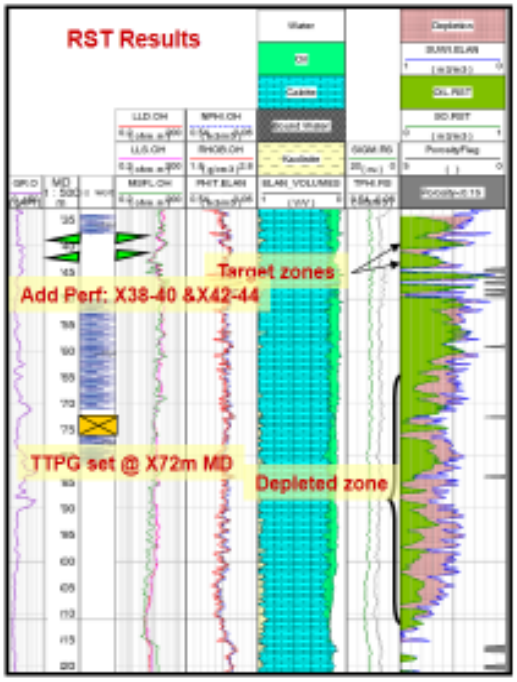
Conclusions

- Judiciously planned rig less job is a cost effective way for incremental oil and reduction in water cut. A net oil gain of close to US$ 3 million in three months from seven intervened wells reflects the cost effectiveness of rig less operations
- Data acquired in a flowing well can be extrapolated for understanding the reservoir dynamics in vicinity wells
- For mapping bypassed oil the initial oil saturations should be accurately computed prior to comparison with current oil saturations obtained through Pulsed Neutron Logging.
- Precise mapping of injection water imprints and bypassed oil through Pulsed Neutron Logging in some wells can serve as a vital tool for future well placements
- Rig less interventions also help in identifying well bore hardware problems to be tackled with rig at a later stage.
- Through Tubing Isolation Plugs can be set across perforations with the strategy developed by the authors and the same will be discussed along with illustrations in few wells. This way many single perforation wells with high water production from bottom part of the interval can be revived by reduction in water cut.

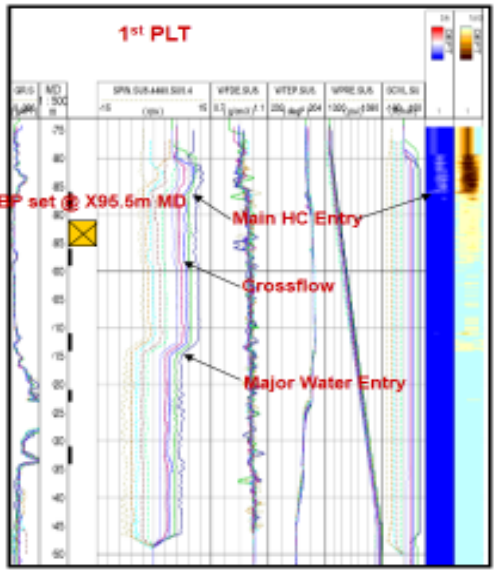
Well – 1

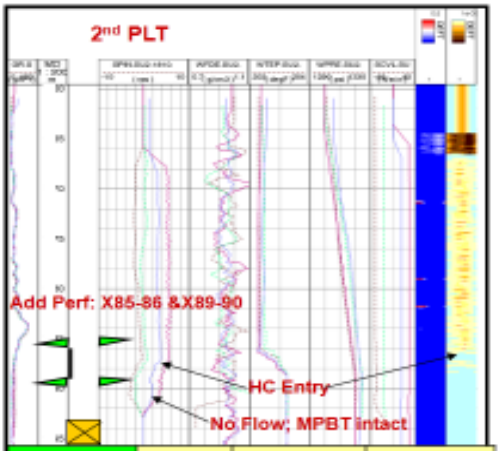
Results	Oil (bpd)	Liquid (bpd)	Water Cut
Pre-TTPG	245	1485	83.5%
Post-TTBP	445	742	40%
Post-Perf	603	1257	52%





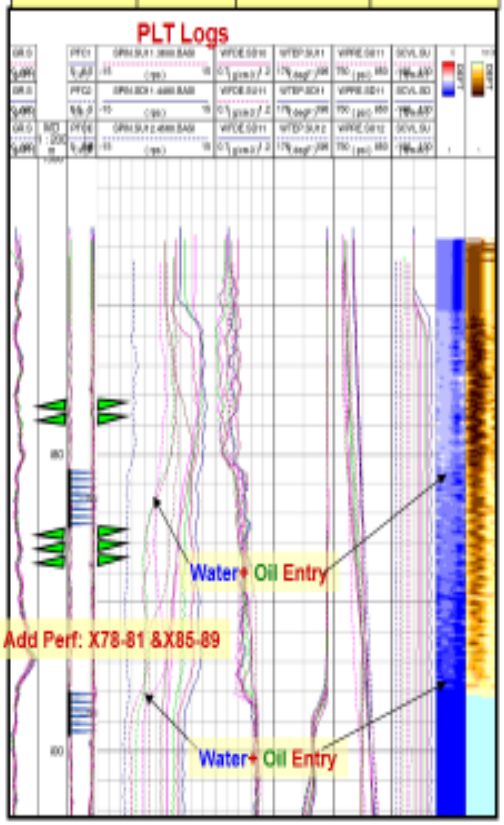
Well – 2





Results	Oil (bpd)	Liquid (bpd)	Water Cut
Pre-Operation	0	Well Shut-in	N.A.
Post-TTBP	154	2646	94.5%
Post-Perf	194	2425	92%

Results	Oil (bpd)	Liquid (bpd)	Water Cut
Pre-Perf	342	1036	67%
Post-Perf	466	1013	54%



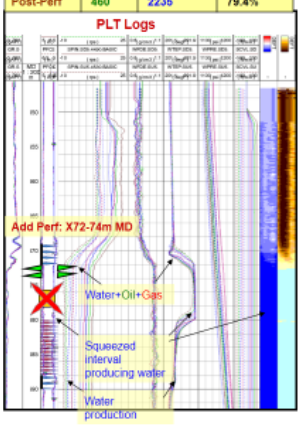
Well - 3

RST was ruled out because of low porosity (<13%) in most of the interval

Since substantial oil was being produced from the bott perforation, MPBT was ruled out.

Additional perforation was carried out at intervals X85-89 and X78-81m MD

Results	Oil (bpd)	Liquid (bpd)	Water Cut
Pre-Perf	258	2395	89.2%
Post-Perf	460	2235	79.4%



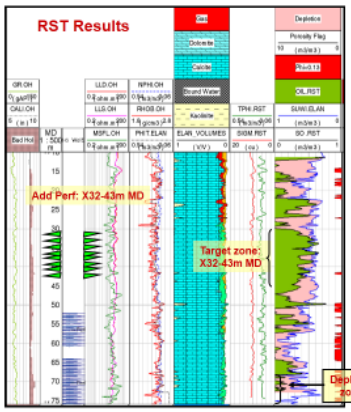
Well - 4

MPBT planned to shut-off the water coming from squeezed zone and below

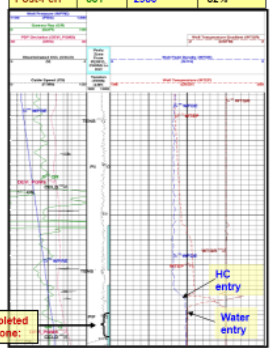
MPBT Cancelled because of Heid-up.

Additional perforation was carried out at intervals X72-74m MD.

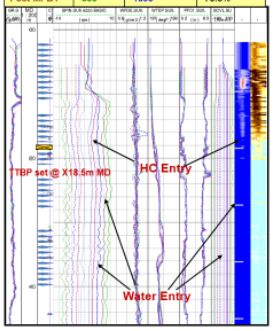
Well - 5



Results	Oil (bpd)	Liquid (bpd)	Water Cut
Pre-Perf	524	2911	82%
Post-Perf	531	2950	82%



Results	Oil (bpd)	Liquid (bpd)	Water Cut
Pre-MPBT	201	1155	82.6%
Post-MPBT	386	1838	78.8%

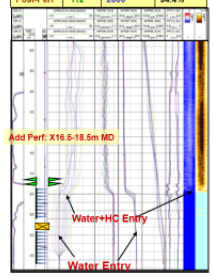


Well - 6

MPBT set @ 1918.5 to shut-off the water coming from Bottom perforations

Well - 7

Results	Oil (bpd)	Liquid (bpd)	Water Cut
Pre-Perf	135	1929	93%
Post-Perf	112	2000	94.4%

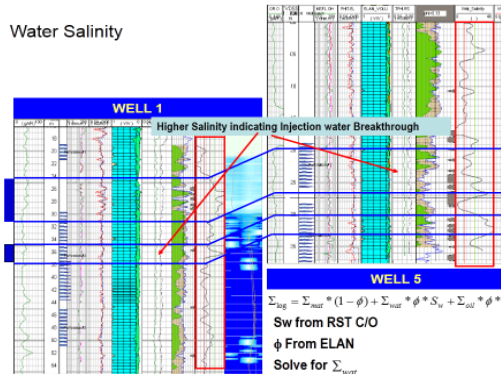


MPBT set @ 1927m MD to shut-off the water coming from Bottom perforation

Additional perforation @ 1916.5-1918.5m MD

Novel approach for mapping footprints of injection water

Water Salinity



$$\Sigma_{log} = \Sigma_{mat} * (1-\phi) + \Sigma_{wat} * \phi * S_w + \Sigma_{oil} * \phi *$$

Sw from RST C/O

ϕ From ELAN

Solve for Σ_{wat}