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Brown Field Production Optimization Using TDT Log for Zonal Isolation, BED 2, Field Western Desert Egypt

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Abstract

BED 2 field is one of the main producing assets for Bapetco company, Western Desert Egypt, BED 2 Field has hydrocarbon accumulations in Abo Roash, Lower Baharyia and, Upper Kharita formations. The field is a multi-reservoir started producing gas from Lower Baharyia and, Upper Kharita formations. The initial value of the field water saturation was calculated using Archie's method where, it reached 20%. After years of production, it was decided to monitor the reservoir and measure accurate water saturation using Thermal Decay Time (TDT) tools as the water cut increased significantly. The tool was run in X-3 well over Lower Baharyia and Upper Kharita formations. The hydrocarbon type is Gas-Condensate; the formation water salinity is well determined leading to decreasing saturation calculation uncertainty. Gas Water Contact (GWC) moved up by 9 meters and water saturation increased in Lower Baharyia and Top Kharita formations. The results revealed that the water production intervals must be isolated, resulting in decreasing of water cut and gas production increasing.

Keywords: Thermal Decay Time; Water Saturation; Gas Water Contact; Archie; Gas Production

1. Introduction

One of the most important factors in reservoir management is an accurate determination of water saturation. This value's accuracy is very critical in time-based measurements used in tracking reservoir contact, depletion, and workover strategies due to water breakthrough effects. This parameter is even more sensitive in gas fields that can significantly reduce production from the field as there is an excessive water management problem with gas (Eyvazzadeh et al., 2004). BED 2 is one of the main producing fields at the northern part of the western desert of Egypt in Abo-El-Gharadig basin, extending about 10 km along NW-SE direction and 3 km across NE-SW. The field is a gas condensate

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located 300 km west of Cairo and 15 km from BED 3 figure (1) and was discovered in 1982. Well X-1the 1st exploration well was drilled 1982 to test Kharita Formation which found water bearing and plugged and abandoned.

X-2, X-3, and X-4 follow up wells were drilled later and a gas-bearing reservoir was discovered in Lower Baharyia and Upper Kharita formations. Additional appraisal wells were drilled up to X-11. These wells have another reservoir in Abo Roash Formation. The field is a multi-reservoir producing gas from Lower Baharyia and Upper Kharita formations, whereas initial water saturation was calculated by Archie saturation method. After years of production, it was decided to monitor the reservoir and measure accurate water saturation using TDT tools. Lower Baharyia and Upper Kharita are vertically connected, have the same aquifer, and have one GWC (Bapetco Report, 2017).

In this mentoring campaign, TDT tool was run in X-3 well over Lower Baharyia and Upper Kharita formations. The hydrocarbon type is Gas-Condensate; the formation water salinity is well determined from water.

2. Geological Setting

The study area covers the northwestern part of the Abu Gharadig Basin including, BED Fields specially, BED 2 Field Concession, The Abu Gharadig Basin is a deep E-W oriented asymmetric graben. It extends for about 300 Km long and 60 Km wide and represents about 3.6% of the Western Desert area, with age ranges from Late Jurassic to Early Cretaceous (El-Toukhy and Bakry, 1988).

In BED Concessions, oil and gas have been produced up to now from the members of the Late Cretaceous (Turonian) Abu Roash Formation, the underlying CenomanianBaharyia and AlbianKharita formations (El-Toukhy and Bakry, 1988).

The Cretaceous is divided into upper and lower sequences. The Upper Cretaceous sequence includes Khoman, Abu Roash and Baharyia formations while the Lower Cretaceous includes Kharita, Dahab, Alamein and Alam El Bueib formations (Hantar, 1990).

Baharyia Formation extends over most of the Western Desert. It rests on Kharita Formation and underlies everywhere the widely spread Abu Roash Formation at an easily recognizable contact provided by the sandstone bed, which is persistently present at the base of the Abu Roash Formation. Baharyia Formation consists mainly of fine-grained sandstones and shale with some thin streaks of limestone deposits in coastal to shallow marine environments (Hantar, 1990).

Kharita Formation extends over most of the Western Desert. It conformably rests on the Dahab Shale. In wells where the Dahab Shale is absent, it rests on the Alamein Dolomite or the Alam El-Bueib Formation. It underlies everywhere the widely spread Baharyia Formation at the easily recognizable contact provided by the limestone bed, which is persistently present at the base of the

Baharyia Formation. Kharita Formation consists of fine to coarse-grained sandstone with interbeds of grayish-green shale and some carbonates. The sandstone is colorless clean white to light gray medium to coarse grained with rounded grains slightly calcareous with traces of glauconite and pyrite (Hantar, 1990).

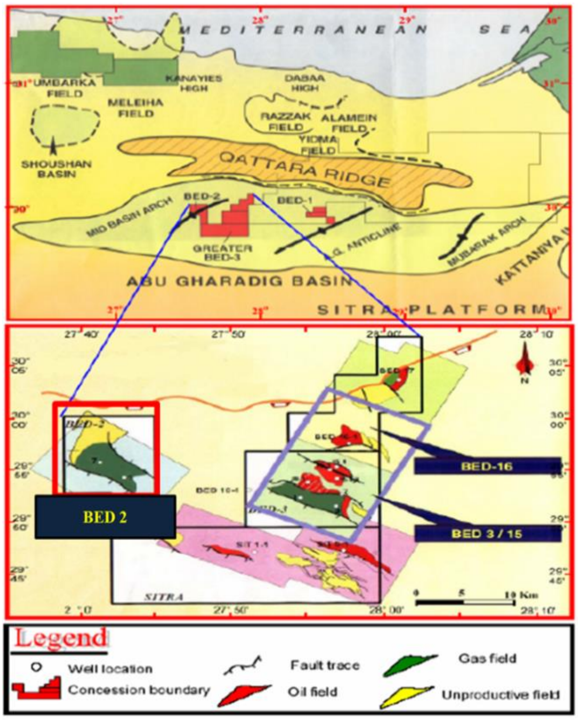

Fig 1: Location Map of the Study Area (Bed-2 Concession Red Boundary) (El-Toukhy and Bakry, 1988).

3. Methodology

Recent advances in TDT logging (Which runs in a cased hole) technology have provided measurements that have become more quantitatively robust in reservoir monitoring projects. Enhancements in tool design, characterization, and interpretation have contributed to an increase in saturation measurement calculations. These innovations have led to major improvements in varied fluid saturation profiles provided by different service companies. These variations are due to differences in tools design and interpretation methodologies **(Petricola, 1996 and Hamada, 2017)**.

The TDT log records the capture rate of thermal neutrons in a formation after it is bombarded with a burst of 14 MeV neutrons. The neutron generator in the tool produces pulses of neutrons, which spread into the borehole and formation. The log is also called pulsed neutron logs or neutron lifetime logs and is often called by various service company abbreviations, include TDT, PNL, NLL, PDK, RMT **(Schlumberger 1984)**.

TDT logging tools introduced earlier in 1960s. have been commercially available since the 1970s. In the 1990s several new generations of tools were introduced by the different logging companies. In comparison to the older tools, these new tools have high output neutron generators with better detectors and characterizations that provide more accurate answers **(Eyvazzadeh et al., 2004 and Hamada, 2019)**.

In TDT, the capture cross-section SIGMA (Σ) is defined as the relative ability of a material to capture free thermal neutrons. Chlorine has a high capture cross-section, while hydrogen has a lower capture cross-section **(Schlumberger 1984)**.

The pulsed neutrons are quickly slowed down to thermal energies by successive collisions with atomic nuclei of elements in the surrounding media. Elements within the formation gradually capture the thermalized neutrons. Gamma rays are emitted with every capture. The rate at which these neutrons are captured depends on the nuclear capture cross-sections, which are characteristic of the elements making up the formation and occupying its pore volume. The capture emitted gamma rays are counted at one or more detectors in the logging tool during different time gates following the burst.

From these counts, the rate of neutron decay is automatically computed. Another result displayed is the thermal decay time, TAU that is the decay time constant for the thermal neutron population, which is related to the macroscopic capture cross-section of the formation, SIGMA, also displayed **(Schlumberger, 1984 and Pemper, 2021)**.

One of the key elements in successful TDT interpretation is pre-job planning, formation water salinity, borehole conditions, porosity, casing condition, cement condition, and completion restrictions must be considered before any job.

The following equation was used to estimate the water saturation from TDT log **(Bateman, 2015)**:

$$Sw = [(\sum log - \sum ma) - \Phi(\sum h - \sum ma) - Vsh(\sum sh - \sum ma)] / \Phi (\sum w - \sum h)$$

Where:
Sw = Water Saturation;
Φ = Porosity;
∑log = Sigma log reading (CU);
∑ma = Sigma matrix value (CU);
∑h = Sigma hydrocarbon (Gas) From Charts;
∑sh = Sigma shale;
∑w = Sigma water from Charts;
Vsh = Shale volume.

4. Data Analysis and Results

BED 2 field is producing gas condensate from Lower Baharyia and Upper Kharita Formation. Pressure data indicate that both formations are vertically connected and share the same fluid contact. Initial Free Water Level "FWL" at 2495 m TVDSS was interpreted from RFT pressure data analysis **(Bapetco Report, 2017)** , which matches the interpreted GWC from open hole logs. Monitoring changes in GWC due to production is a key factor to maximize production, well lifetime, and recovery per well. For those reasons "TDT"-(Halliburton RMT) tool was run against Lower Baharyia and Upper Kharita reservoirs in X-3 well to determine current GWC and hydrocarbon saturation.A large-scale reservoir monitoring project is initiated in all Bapetco fields started in with BED 2 Field. X-3 well was chosen to define the current GWC and hydrocarbon. This choice was selected based on criteria given below to be the first well in the TDT campaign in BED 2 field:

- Good borehole conditions;
- Known lithology and porosity;
- Complete set of logs;
- The ability to Shut in and flow the well;
- No mechanical restrictions (Tool size, casing , tubing);
- Good reservoir quality;
- Extensive laboratory core data.

Sigma water of 76 cu was estimated from the measured formation water salinity of 132 KPPM (figure 2).

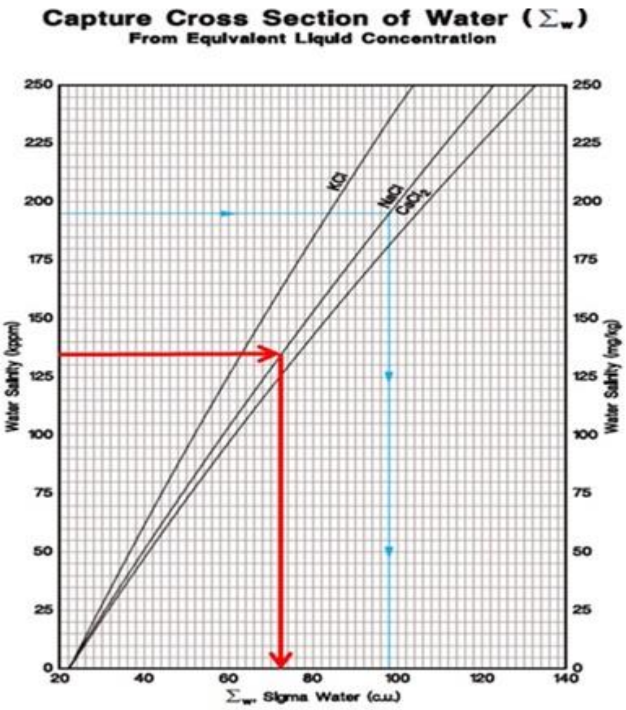

Fig 1: Σw from Halliburton Log Interpretation Chart Book using fm water salinity.

Sigma gas "hydrocarbon" of 2 cu was estimated (figures 3 and 4) from Halliburton 2000 using the current reservoir pressure, temperature and gas specific gravity (tables 1 and 2).

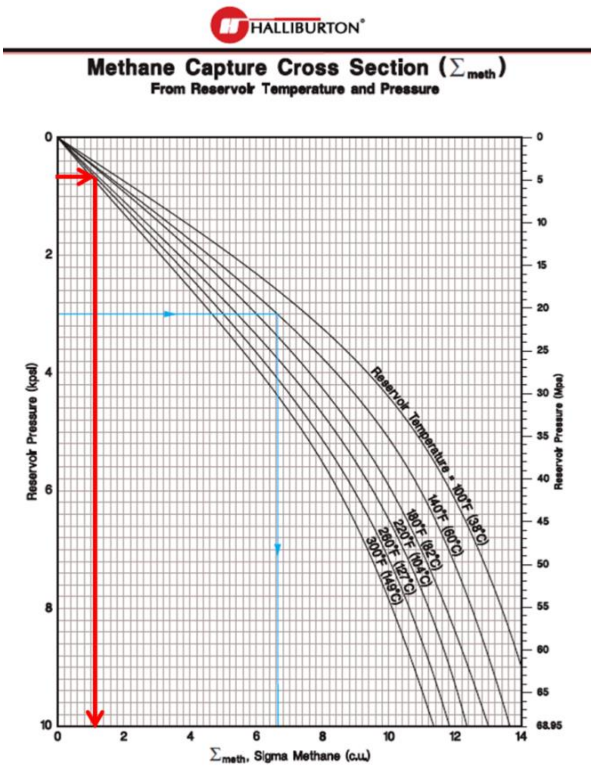

Fig 2: Σ Methane from Halliburton Log Interpretation Chart Book using Pressure measured in 2014.

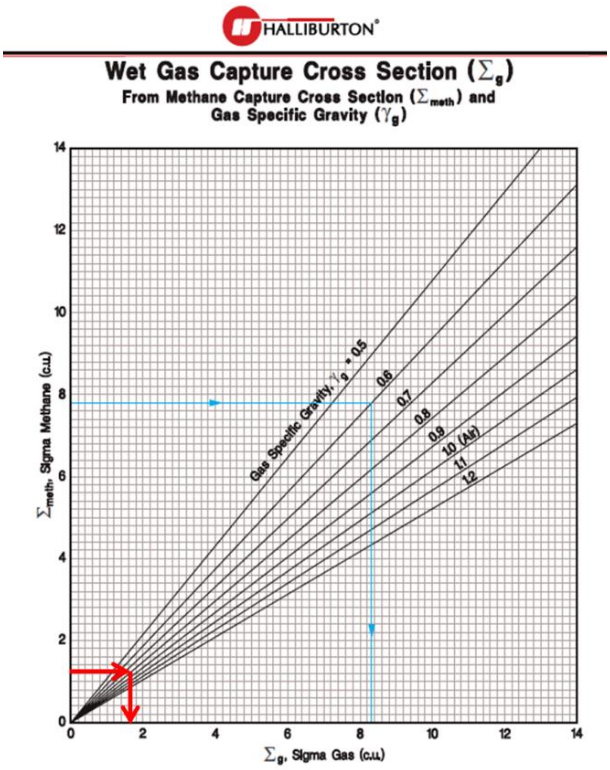

Fig 3: Σgas from Halliburton Log Interpretation Chart Book using ∑Methane and produced gas specific gravity.

Sigma shale of 31 cu was estimated from TDT "sigma" log against shale interval.

Lower Baharyia and Upper Kharita are vertically connected, and have the same GWC and then the same parameters as shown in tables (1 and2).

Table 1 the required data used to estimate Sigma water and sigma hydrocarbon.

Formation	Formation Water Salinity (PPM)	Measured Pressure 2014 (TDT) time (PSI)	Temperature (F)	Gas Specific Gravity ɣ
Lower Baharyia	132000	620	200	0.845
UpperKharita	132000	620	200	0.845

Table 2

The estimated sigma water, gas and shale.

Formation	∑w	∑Gas (Hydrocarbon)	∑sh
Lower Baharyia	73	1.8	31
UpperKharita	73	1.8	31

TDT was interpreted and correlated with the open hole logs showed that the water saturation increased dramatically in Kharita Formation and the GWC moved up around 9 meters due to production, while in Lower Baharyia, the water saturation is relatively increased with production, the GWC moved upward by 9 meters.

The decision was taken to isolate the lower set of perforations in Lower Baharyia, which, is the main source of water in X-3 well and continues production from Lower Baharyia upper perforations.

After isolation, the water cut dramatically decreased in X-3 well and gas production increased. Figure 5 shows the change in initial water saturation calculation from Open Hole (OH) logs and the current water saturation calculated from TDT log.

The zone of interest in figure 5 is magnified in figure 6 which shows the change in sigma reading as it increases gradually against resistivity decrease and the current water saturation calculated from TDT log shows some residual hydrocarbon saturation at the moved contact zone from 2495 to 2486 m TVDSS.

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Tracks from Left are: 1) Bit Size and caliper log; 2) Gamma ray; 3) Shale volume; 4) Measured depth; 5) True vertical depth subsea; 6) Perforation Intervals; 7) Neutron – Density log; 8) Deep resistivity log; 9) Porosity; 10) Water Saturation from Archie equation; 11)

Water Saturation from Sigma TDT log; 12) Sigma Reading; 13) Pressure; 14) Mobility; 15) Formation Tops.

Equations

$$Sw = [(\sum log - \sum ma) - \Phi(\sum h - \sum ma) - Vsh(\sum sh - \sum ma)] / \Phi (\sum w - \sum h)$$

Where:

Sw = Water Saturation;

Φ = Porosity;

∑log = Sigma log reading (CU);

∑ma = Sigma matrix value (CU);

∑h = Sigma hydrocarbon (Gas) From Charts;

∑sh = Sigma shale;

∑w = Sigma water from Charts;

Vsh = Shale volume.

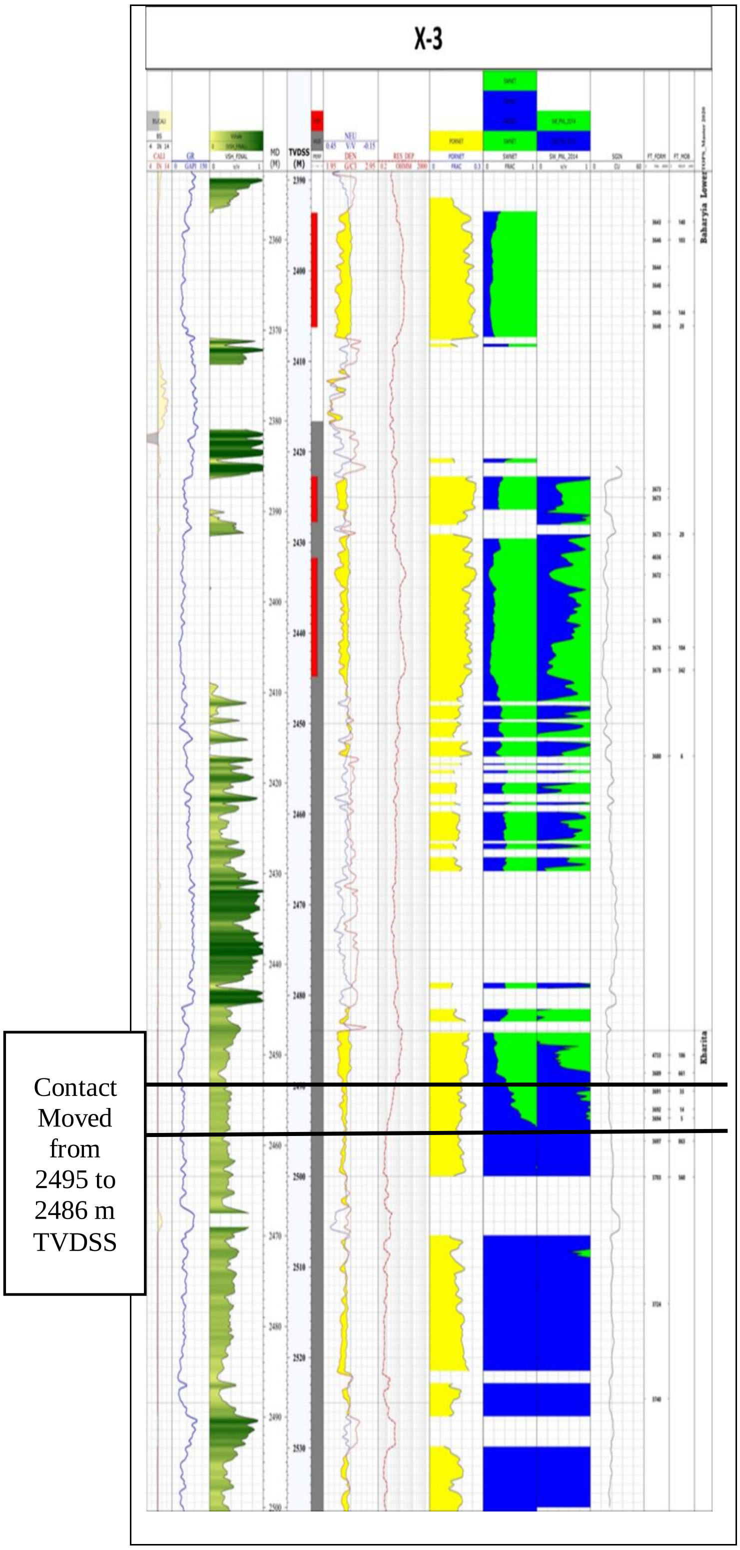

Fig 4: X-3 TDT log interpretation With OH log interpretation.

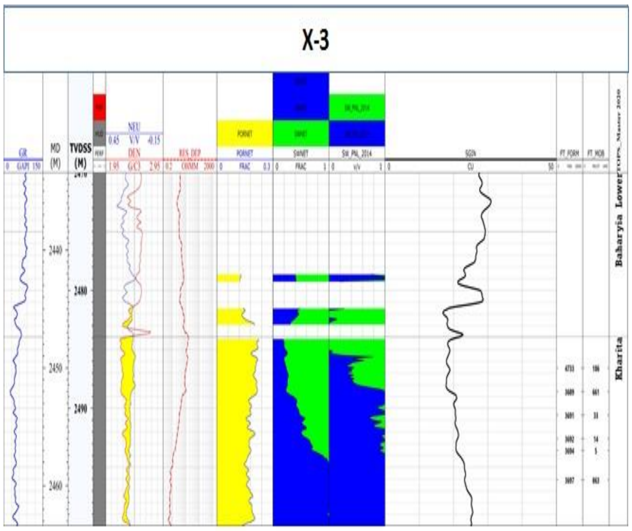

Fig 5: X-3 TDT interpretation With TC interpretation Showing Sigma Change Effect.

5. Conclusions

BED 2 field is one of the main producing assets for Bapetco Company in Egypt. The field is producing gas condensate from Lower Baharyia Formation. A large-scale reservoir monitoring project is initiated in all Bapetco fields. The BED 2 field started with defining current GWC and hydrocarbon saturation after the appearance of water cut with production. One of the key elements in successful TDT interpretation is pre-job planning, formation water salinity, borehole conditions, porosity, casing condition, cement condition, and completion restrictions that need to be considered before any job.

To address the problem of increasing water production and decreasing gas production rate from the field significantly, the optimum solution, in this case, is to monitor changes in GWC determined initially from RFT data. After running TDT log (RMT Halliburton Tool), GWC level changes are confirmed from well X-3. TDT evaluation showed that the initial contact is moved up from 2495 to 2486 m TVDSS by 9 meters in the Upper Kharita Formation. Also, lower set perforations in Lower Baharyia flushed with water as the water cut increased. It was recommended to isolate the perforations in this zone and add perforations in the sand body above isolated perforations. After new perforations, gas production increased without water cut. TDT log results were very conclusive for zonal isolation decisions in the field.

6. Conflicts of interest

In accordance with our policy on Conflict of interest please ensure that a conflicts of interest statement is included in your manuscript here. Please note that this statement is required for all submitted manuscripts. If no conflicts exist, please state that "There are no conflicts to declare".

7. Acknowledgments

- The manuscript has not been submitted to other journals for simultaneous consideration.
- The submitted work is original and have not been published elsewhere in any form or language (partially or in full).
- This study has not been split up into several parts to increase the quantity of submissions.

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