EVALUATION OF WATER SATURATION IN THE LOW RESISTIVITY RESERVOIR OF TE GIAC TRANG FIELD, BLOCK 16-1, CUU LONG BASIN, OFFSHORE VIETNAM

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Summary

It is well known that there is a series of oil fields in the Cuu Long basin that were discovered in low resistivity Early Miocene sequences, and the Te Giac Trang field is a case that challenges formation evaluation for water saturation of the pay sands in the reservoirs. It is believed that the low resistivity is a result of the effects of many factors such as thin beds, the low degree of sand compaction, the presence of highly conductive minerals (pyrite etc.), and montmorillonite that significantly increases the surface conductivity, sorting of the sand and type of cement.

In the Te Giac Trang field, for the water saturation calculation, an approach was used with the traditional shaly sand model and modified Archie equation constants. The said method combined with the results of pressure pretests allows us to minimise the uncertainty of the estimated water saturation for these low resistivity pay sands.

Key words: *Early Miocene, low resistivity, J function, clay, thin bed, water saturation, pressure, high permeability, low permeability, Te Giac Trang field.*

1. Introduction [1 - 3, 6 - 10]

The Early Miocene sequence is the second big oil zone after the basement section and oil is produced from low resistivity sandstone reservoirs of the Bach Ho formation in the Te Giac Trang, Bach Ho, Rong, and Su Tu Den fields.

The Te Giac Trang field is located in Block 16-1 of the Cuu Long basin, approximately 120km from Vung Tau city. The Hoang Long Joint Operating Company (HLJOC) is licensed to operate this block. The field targets multi-pay objectives within the primary target Early Miocene Bach Ho formation (BI.1 sequence) sandstones and the secondary target Late Oligocene Tra Tan formation (C sequence) sandstones.

The Te Giac Trang field is divided into H-1, H-2, H-3, H-4 and H-5 by fault blocks and lies along a south-plunging regional scale anticlinal trend, crossed by E-W faults and a subordinate set of SW-NW faults.

The Early Miocene (BI) sequence is subdivided into Late Bach Ho (BI.2) and Early Bach Ho (BI.1). The Late Bach Ho sediments were deposited in shallow and open marine environments. The Early Bach Ho, deposited in coastal, fluvial, deltaic and shallow marine environments, is subdivided into three units: ULBH, ILBH5.1 and ILBH5.2. Well log practice identified low resistivity contrast subsequences. Low-resistivity pay is generally characterised by pay zones that cause deep resistivity log curves to read from 0.5 to 5Ω.m. This is often attributed to a combination of shale content, mineralogy, microporosity, grain size and bed thickness.

Low-contrast pay implies a lack of resistivity contrast between pay sands and adjacent shales or wet zones. This problem is most commonly seen when the resistivity tool encounters a zone that contains fresh water (or water of low salinity). As salinity decreases, the electrical pathway through a body of water becomes weaker and more dispersed, thus causing the water to become less conductive (or conversely, more resistive). Therefore, while the resistivity of the pay zone may not be low, the resistivity of the water leg is high enough to make it difficult to distinguish between pay and wet zones. However, in the Te Giac Trang field the water salinity is very high, in this case low contrast pay implies a lack of resistivity contrast between pay sands and adjacent shales.

A number of factors have been found to act on the logging tool to produce low resistivity or low contrast pays, including the following:

- Bed thickness: some pay zones are simply too thin to be resolved by the logging tool.

- Mineralogy: conductive minerals (such as pyrite, glauconite, hematite, or graphite, smectite, illite, chlorite, kaolinite) or rock fragments can have a pronounced effect on resistivity response.

- Structural dip: dipping beds produce significant excursions on the resistivity log when orientation between the tool and the bed deviates from normal.

- Clay distribution: classified as either dispersed, structural, or laminated - all capable of holding bound water.

- Water salinity: high salinity interstitial water causes low resistivity within the pay zone, while low salinity water can cause low contrast pays.

- Grain size: very fine grain size can lead to high irreducible water saturation.

Any combination of the above: often a combination of inter-related factors causes the logging tool to read lower resistivity than normal inside a pay zone.

In the Te Giac Trang field, probably the most common cause of low resistivity pay is the simple combination of thin beds containing highly conductive shales (and their associated bound water), along with thin pay sands which are below the vertical resolution of the logging tool, as shown in Fig.1, below, of conventional core through a laminated interval in the Early Miocene sequence. It is observed that there were certain amounts of conductive mineral such as pyrite found in the core sample, which definitely play some role in the low resistivity nature of the Early Miocene reservoirs.

The presence of clay causes a conductive path due to the presence of an excess of cations clinging to negatively charged clays. The movement of cations along the surface of the clay constitutes an electrical path. The larger surface area of clays presents more Cation Exchange Capacity, thus lowering the resistivity of the hydrocarbon sands. The Table 1 shows the abundant presence of all the clay minerals, particularly smectite that is the main cause of low resistivity in the hydrocarbon zones.

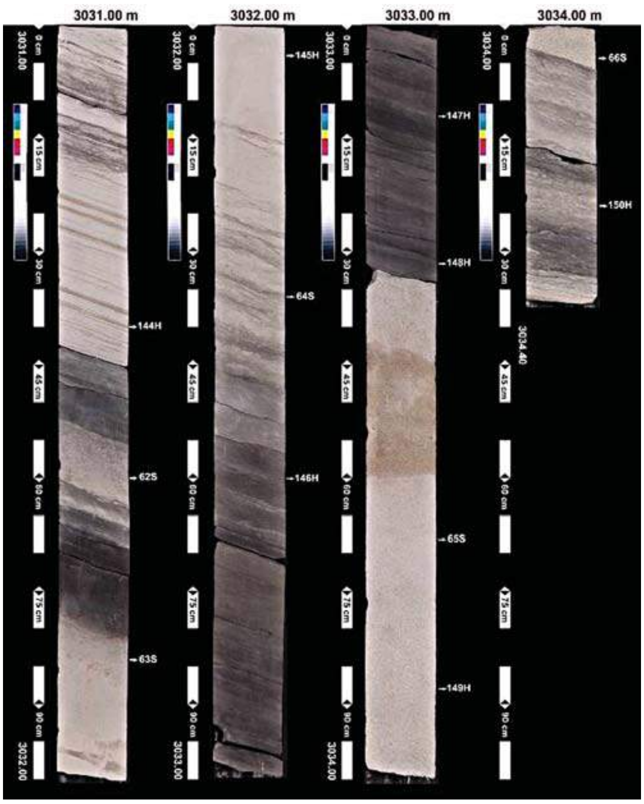

***Fig.1.** Core through a laminated interval in the Te Giac Trang field*

In the Early Miocene reservoirs in the Te Giac Trang field, the sandstones are thinly interbedded with the low resistivity shales. It is commonly observed that the sandstones thicknesses are less than the tool's vertical resolution. Even with thicker sand layers, the resistivity readings are normally affected by bedded claystones. As a result, the resistivity readings of the oil bearing sandstones are lower than they should be. Pyrite is a very good conductive matrix. If pyrite was present in the formation, the measured resistivity of the formation would be affected by conductive pyrite. Traces of pyrite have been observed in low Miocene sequence. This is an additional factor causing the low resistivity values in hydrocarbon zones.

All of the list above cause low resitivity contrast pay. Even if all of the above data were taken into account for saturation calculation, it would not necessarily provide more accurate estimates of water saturation due to a lot of uncertainties. The Model Saturation - Height Pc from J function is to be used in this case.

2. Using J function to calculate water saturation in Te Giac Trang field [1 - 4]

J function is a master curve that can be used to represent reservoirs of similar rock type. In the Te Giac Trang field, based on the permeability range of the test samples, there are two kinds of J functions that have been created from quality-controlled refined legacy porous plate data. Power law regressions of form were fitted to "high permeability" and "low permeability"

$$Sw = \frac{a}{J^b}$$

***Table 1.** The result of XRD analysis for clay fraction (< 2 microns)*

MD (m)	Kaolinite (%)	Chlorite (%)	Illite (%)	Smectite (%)	Mixed layer of illite-smectite (%)
2,799.0	16.7	12.6	10.6	57.9	2.2
2,827.0	20.5	36.4	24.6	14.0	4.5
2,839.5	46.8	17.2	12.0	18.1	5.9
2,914.0	24.6	16.7	25.8	28.2	4.7
2,934.0	32.4	22.4	14.7	26.5	4.0

***Table 2.** The results of XRD analysis for SWC show conductive mineral*

MD (m)	Quartz (%)	K-Feldspar (%)	Plagioclase (%)	Mica and/or other clays (%)	Kaolinite and/or Chlorite (%)	Calcite (%)	Epidote (%)	Pyrite (%)	Sylvite and Halite (%)
2,839.5	49.5	16.6	14.3	5.8	11.1		1.3	1.0	0.4
3,066.5	43.3	11.2	25.8	3.2	13.6		1.3	1.0	0.4
3,116.5	28.9	11.1	17.7	15.4	24.4		1.0	0.9	0.5
3,174.5	40.8	30.1	17.2	2.1	6.6	1.5	0.7	0.9	0.3
3,181.0	43.4	23.5	21.2	2.0	7.6		1.2	0.7	0.4
3,220.0	70.2	5.9	4.3	12.4	5.0	0.6	0.6	0.6	0.6
3,297.5	43.2	15.3	19.2	2.0	17.0	0.8	1.2	0.9	0.5
3,415.0	57.8	13.5	15.2	3.4	8.3		0.7	0.6	0.5
3,425.0	60.3	13.3	15.0	2.1	7.7		0.6	0.6	0.4

***Table 3.** The water-mud filtrate samples analysis salinity*

No	Oil gravity (°API)	Water resistivity 25°C (Ω.m)	Salinity 25°C (ppm)
1	41.7	0.1100	59,259
2	39.8	0.0779	90,269
3	39.4	0.1536	40,533
4	39.1	0.1195	54,098
5	39.9	0.0738	96,579
6	40.5	0.0871	78,748
7	35.8	0.0641	115,487

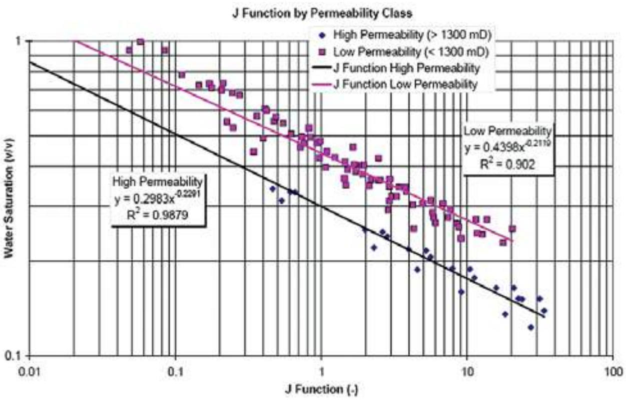

***Fig.2.** Relationship between J function and saturation*

In Fig.2, the permeability J function extrapolation by setting Pc = 0.01 psi at Sw = 100%.

J functions are as below:

Low Permeability (< 1,300mD)

$$Sw = \frac{0.4398}{J^{0.2119}}$$

High Permeability (> 1,300mD)

$$Sw = \frac{0.2983}{J^{0.2291}}$$

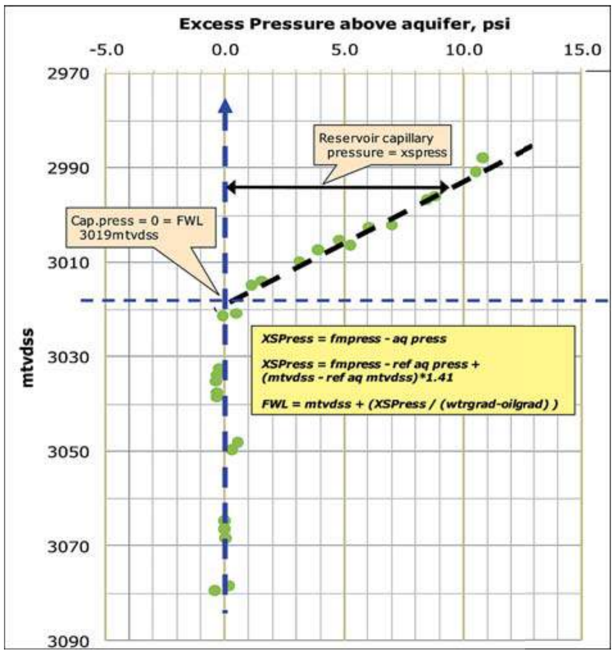

***Fig.3.** Excess pressure above FWL*

Both of the J functions are converted to Height above the free water level as below:

$$Sw = \frac{a}{\left[\left(\frac{0.2166\,x\,(\rho_w - \rho_o)\,x\,H}{\sigma\,x\cos\theta_{res}}\right)\sqrt{\frac{K_a}{\phi}}\right]^b}$$

Where:

ρ_w: Water density gradient (0.428psi/ft),

ρ_o: Oil density gradient (0.29psi/ft),

σ x $\cos\theta_{res}$: Adhesion force at reservoir conditions (σ = 14 - 20dynes/cm, θ = 30°),

H: Vertical height above free water level (FWL) by excess pressure (ft),

Sw: Water saturation (%).

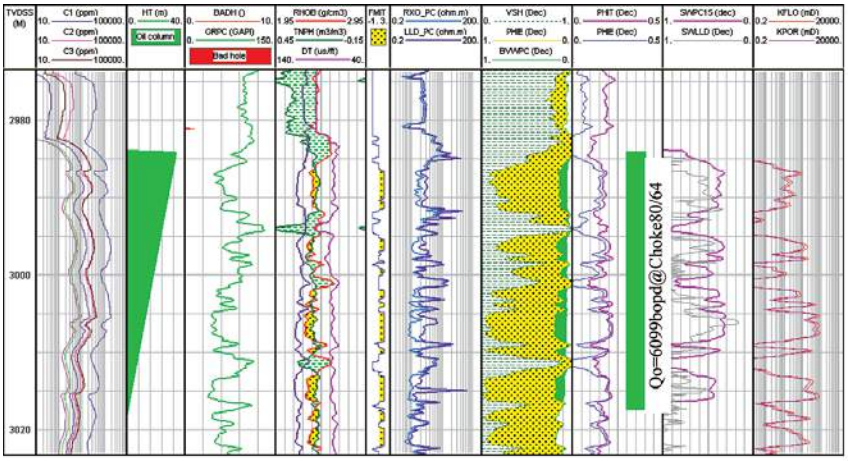

Fig.4. *Saturation estimated in the low resistivity zone*

The above figure shows us, if a shaly sand model is applied to compute water saturation taking into account all of the data, the average water saturation in pay zone is 59.8% and this result is higher than water saturation from Excess Pressure integrated with conventional log model, average water saturation (36.5%) in the pay zone. This value's greater accuracy is confirmed by DST results with Q_o = 6,099 barrels of oil per day (choke 80/64" without formation water free).

3. Conclusion

In conclusion, the complexity of clay distribution, bed thickness, mineralogy, depositional environment and rock heterogeneity can play a major role in causing low resistivity contrast in the Early Miocene reservoirs which will lead to wrong water saturation estimation by using the shaly sand model. HLJOC introduced a method which uses the Excess Pressure integrated with conventional log derived information to indicate reliable water saturation that is vital to identify high grade zones to perforate and to ensure maximum production and ultimate recovery.

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