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Improved Prediction of Fluid Contacts using Calibrated Material Balance Models

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ABSTRACT: The demand for oil has been on the high in the recent past and will continue as search for sustainable alternative energy sources intensifies. The exploration and exploitation of oil from subsurface reservoirs have posed several environmental challenges which include flaring and improper water disposal to name a few, caused by excessive production of gas and water. Hence it is important to establish a reservoir performance monitoring scheme that will ensure that appropriate fluids are produced from the reservoir within the economic producing life of each well draining a given reservoir by monitoring the fluid contact levels. Furthermore, appropriate reservoir monitoring will help to improve productivity and recovery of old wells, calibrate predictive reservoir models and identify opportunities for optimum reservoir development. A key tool used in reservoir performance monitoring is the post production log, particularly the Pulsed Neutron Capture (PNC) and Pulsed Neutron Spectroscopy (PNS) logs which make use of high energy neutrons to determine the fluid contacts in the reservoir. This campaign however is very expensive; hence an alternative and less expensive method of determining and predicting the present and future fluid contacts will be discussed. This involves using calibrated material balance models to predict the fluid contacts based on the pore volume (voidage) replacement by the displacing fluid. This will help in generating fluid contacts on a more frequent time interval.

KEYWORDS: Prediction, Fluid Contacts, Calibrated Material Balance Models.

INTRODUCTION

Usually, in an oil reservoir which is associated with a gas cap and an underlying aquifer, it is extremely to ascertain the fluid contact levels that separate the gas from the oil (GOC) and the oil from the water (OWC). This is usually done just as the well is being drilled (logging while drilling) or after the well has been drilled (wireline logging) through a process known as well logging. This involves deploying tools that pick up electrical, magnetic, sonic, and radioactive responses from the reservoir. These signals are transmitted via the conductive drillstring or wireline to the surface where they are processed and interpreted to generate several rock and fluid properties including the fluid contacts. This is illustrated in Fig 1. Data generated from interpretation of log results serve as key input for numerous reservoir and geologic models.

Of these parameters, the fluid contacts play a major role in decision making on where to complete a well. This will go a long way in determining how soon undesirable water and/or gas will breakthrough into the wellbore. Before production is initiated, the reservoir is at a steady state and the fluid contacts are in static equilibrium as a result of gravity segregation. Once flow of oil into the wellbore commences, the produced oil leaves a void in the pore volume of the reservoir rock which is filled by water encroaching from any adjoining aquifer, a process commonly referred to as water influx. This will continue as the oil is being displaced for a strong water drive system. Hence there will be a vertical movement of the oil-water contact making the water to approach the perforation. This also occurs for the gas cap gas which moves vertically downwards towards the perforation. This implies that a time will come when gas/water will break into the wellbore. However, this is not the only source of water production in a well. Several wellbore inefficiencies such as cement damage can cause sippage of water from shallower zones into the well. Also, the water and/or gas breakthrough can be hastened by gas/water coning effects as a result of the production philosophy of the well/reservoir. All these lead to increased water and excess gas production which adds to the production costs and gives room for improper treatment and disposal.

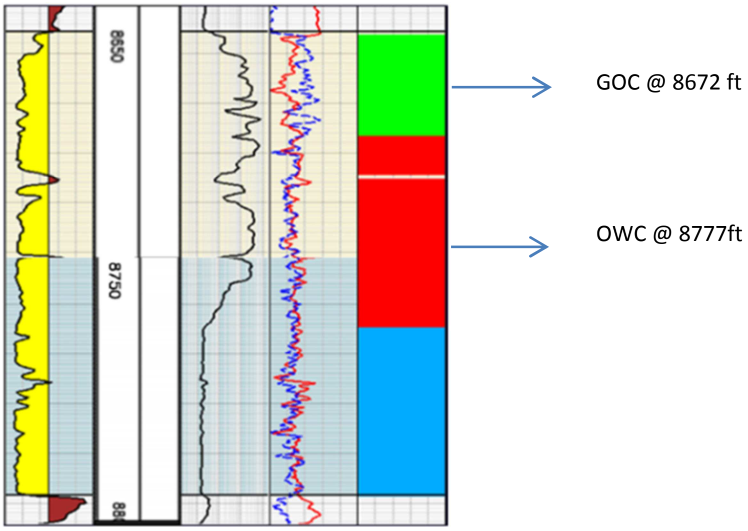


Fig 1: Original fluid contact determination using logs

Since the fluid contacts in the reservoir change with time, it is obvious that a method of estimating the present gas-oil contact (PGOC) and present oil-water contact (POWC) is important so as to aid in planning for workover and understanding the source of water production in the well.

Due to the fact that the wellbore has casing, cement and tubing during the production period of the well, the tools used in to determine the fluid contacts the reservoir in the openhole environment prior to completion will not produce accurate representations of the reservoir. Hence another set of tools called the Pulsed Neutron Capture (PNC) and Pulsed Neutron Spectroscopy (PNS) logs are applied for the determination of the saturation and position of the different fluid phases present in the reservoir at the time of logging.

BRIEF SUMMARY OF PNC AND PNS LOGS

The pulsed neutron logs are the most important devices for formation evaluation through casing. These devices have pulsed neutron sources that emit a burst of 14 million electron volts of neutrons periodically at about 1000 microseconds intervals into the formation. These neutrons interact with the reservoir causing gamma ray emissions of distinct energies at characteristic time intervals depending on the atomic number of the reservoir particles, which may be detected by some electrodes positioned above the neutron source (Fig 2).

Within the first tens of microseconds, high energy inelastic collisions occur. Gamma rays emitted during this period are important for PNS (carbon/oxygen) measurements, but not to capture logging. From this time to about 1000 microseconds or longer, the neutrons are attenuated and become low energy neutrons which are easily captured. A capture event occurs upon collision with certain nuclei in the environment accompanied with emission of a gamma ray. The rate of such capture is a result of thermal neutron collision with the hydrogen and chlorine and is of prime importance in PNC logging.

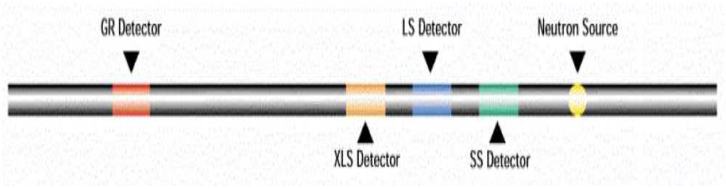


Fig 2: Pulsed Neutron tool arrangement

These low energy neutrons are captured by various formation materials at different rates. The measure of the probability of capture of a thermal neutron by a formation material is its capture cross section in sigma or capture units (c.u.). It is this concept that is used to delineate between the different fluid types in the reservoir. However, fresh or low salinity water (20-24 c.u.) and oil (21 c.u.) have very close sigma values and would be very difficult to discriminate from each other. Hence fresh water looks like oil to capture tools. Since the tool responds to the hydrogen content of the reservoir, gases usually possess low sigma values of about 10 c.u. Hence the capture logs can be used to differentiate between gas and other fluids present in the reservoir.

To differentiate between oil and water, the carbon/oxygen (C/O) or PNS measurements are utilized during the inelastic collision periods. The ratio of the carbon to oxygen interpreted for such signal can be used to differentiate zones of oil saturation from those of water. High C/O ratio indicated high oil saturation and low values will indicate high water saturation.

Interpretation of these logs help in determining the position and levels of gas, oil, and water saturations in the reservoir. They find numerous applications in the petroleum industry such as in the delineation of PGOC and POWC and subsequent determination of the remaining hydrocarbon in place, identification of water shut off and workover opportunities, generation of remaining oil and gas surveillance maps, improved understanding of subsurface dynamics and drive mechanisms, and calibration of predictive reservoir models. Due to their immense importance in proper reservoir monitoring, it is always common practice to engage in periodic pulsed neutron formation evaluation campaign at least every 3-5 years so as to ascertain the state of the reservoir at any point in time. Despite the immense role these logs play, companies do not engage in periodic evaluations due to cost implications of such campaigns which usually run into millions of dollars.

Therefore, some alternatives have been mooted over the past few years to evaluate the PGOC and POWC of a producing reservoir. These include the 4D-seismic and the use of material balance models. 4D-seismic data is a type of time lapse data. It is simply a three dimensional (3D) seismic data acquired at different times over same area to assess changes in a producing hydrocarbon reservoir with time. These changes may be observed in fluid location and saturation, pressure and temperature. This technique is however still at its infancy and is not heavily used in such basins as Niger Delta. Though it shows promising advantages over the conventional pulsed neutron logs, it still does not predict future variations in fluid contact levels.

MATERIAL BALANCE APPLICATION TO RESERVOIR MONITORING

The concept of material balance, introduced by Schilthius in 1936 is the reservoir engineer's tool for interpreting and predicting reservoir performance, based on the law of conservation of mass. Material balance equation is the equation derived as a volume balance which equates the cumulative observed production, expressed as underground withdrawal to the expansion of the fluids and rock in the reservoir resulting from a pressure drop. Oil, gas, and sometimes water are produced when wells are drilled into a hydrocarbon reservoir. Given that petroleum reservoir has a constant volume, the fluid withdrawal results in pressure decline and consequently causes expansion of the reservoir rock, expansion of the remaining oil and gas in the reservoir, invasion of gas from free gas cap and influx of water for adjacent or underlying aquifer.

Hence,

Total Withdrawal = Oil produced + free gas produced + water produced (1)

In material balance applications, it is important to note that several assumptions were considered in generating the equations, which include;

- Reservoir is a homogeneous tank. The pressure, temperature, rock and fluid properties are the same throughout the reservoir.
- The reservoir is zero dimensional, meaning that fluid production and injection occur at single production and injection points.
- The reservoir pressure at any time is the average pressure of the entire system.
- The PVT data used in material balance are accurate
- Adequate and valid production and pressure data exists.

Of importance is the ability of material balance to predict an estimate of fluid contacts of a producing reservoir, an alternative to the pulsed neutron logs. To do this, a material balance model is built which predicts future production to estimate the quantity of oil leaving the reservoir. For a water drive reservoir, according to material balance, an equal volume of water replaces the oil produced giving rise to a cumulative change in the OWC. This also applies to a gas cap driven reservoir where the GOC advances downwards according to the withdrawal. It is this voidage replacement in the reservoir that leads to change in the fluid contacts. Material balance can be used to calculate the voidage replacements which can be in the form of water or gas influx.

Pore volume occupied by net water influx is given by;

$$\text{Net water influx} = W_e - W_pB_w \tag{2}$$

Similarly, provided that no gas is produced from the gas cap gas during pressure decline, the pore volume occupied by gas cap at a reservoir pressure, P (lower than the initial pressure, *Pi*) due to expansion is given by

$$\text{Volume of gas cap} = \left[\frac{MNB_{oi}}{B_{gi}}\right]B_g \tag{3}$$

During production, some dissolved gas in the oil will come out of solution below the bubble point pressure of the reservoir and will add to the pore volume occupied by gas. Hence,

Volume of evolved solution gas = volume of gas initially in solution – volume of gas produced – volume of gas remaining in solution

Mathematically,

$$\left[NR_{si} - N_pR_p - \left(N - N_p\right)R_s\right]B_g \tag{4}$$

The general material balance equation is written as

$$N = \frac{N_p\left[B_t + \left(R_p - R_{si}\right)B_g\right] - \left(W_e - W_pB_w\right)}{\left(B_t - B_{ti}\right) + mB_{ti}\left[\frac{B_g}{B_{gi}}\right] + B_{ti}(1+m)\left[\frac{S_wC_w + C_f}{1 - S_{wi}}\right]\Delta P} \tag{5}$$

PORE VOLUME VERSUS DEPTH

Material balance analysis for reservoirs is based on treating the reservoir as a dimensionless tank. Traditionally, this does not allow account for fluid contact movements, as no geology is provided. Calculations based on classical material balance will allow for the increase in invading fluid saturation as a single number since there is no variation of the fluid saturation in the reservoir. However, by introducing a concept where the pore volume at given depths are known, the contact movements can be calculated. Since pore volume is directly related to the saturation of the fluid phases in the reservoir, which are related to the given depths, the pore volume changes will correspond to saturation and contact changes.

When water encroaches into the reservoir, the water saturation increases and this increase is related to a pore volume fraction. Therefore, the increase in OWC can be calculated based on the pore volume versus depth data which is usually generated from digital map data containing reservoir description information such as the formation tops, sand thickness, porosity and water saturation. This can help describe the relationship between reservoir volume and depth for purposes of accurately modelling reservoir fill-up due to aquifer influx.

To illustrate this, the following terms are to be defined;

Amount of oil remaining in the reservoir, $V_{or} = (N-N_p)*B_o$ (6)

Below GOC,

$$\text{Pore Volume Fraction} = \frac{Pore\ Volume\ from\ top\ of\ oil\ column\ to\ depth\ of\ interest}{Total\ oil\ column\ pore\ Volume} \tag{7}$$

Above GOC,

$$\text{Pore Volume Fraction} = \frac{-(Pore\ Volume\ from\ top\ of\ oil\ column\ to\ depth\ of\ interest)}{Total\ gas\ cap\ pore\ Volume} \tag{8}$$

In calculating the fluid contacts, the pore volume swept by the appropriate phase is calculated using material balance equations. With the pore volume versus depth data, the corresponding depth of the contact can then be determined.

When oil production occurs as a result of pressure decline, it is expected that the produced oil is replaced by encroaching water and gas, the amount of which depends on the strength of the drive mechanism. When gas encroaches into the oil zone, a residual amount of oil saturation, S_{org} is left behind. For the water movement, S_{orw}, which is the residual oil saturation with respect to water, is left behind the water front.

Considering the connate water saturation to be constant, the amount of water that encroaches into the oil leg is given by $(S_w - S_{wc})$, while the saturation of oil that can be displaced is given by $(1-S_{wc}-S_{orw})$. Therefore, the pore volume fraction that is replaced by water would be:

$$PV_{water} = (S_w - S_{wc})/(1 - S_{wc} - S_{orw}) \qquad (9)$$

Considering the absence gas initially in the gas cap zone, the saturation of the gas that can displace oil is given by S_g, and the residual oil saturation with respect to gas is Sorg. Therefore, the maximum displaceable oil saturation is given by (1-Swc-Sorg). This implies that the pore volume fraction that can be replaced by gas when there is no production from the gas cap is:

$$PV_{gas} = \frac{S_g}{(1-S_{wc}-S_{org})} \qquad (10)$$

The presence of the residual saturation of oil will further quicken the advancement of the displacing phase. The higher the S_{orx}, the faster the fluid contacts will change. Since material balance considers homogeneity in reservoirs, vertical sweep efficiency constant is introduced to further influence the water and gas displaced PV fraction. This constant depends on generalized dynamic properties of the fluid and thus will dictate the essence of contact movements. Introducing this makes equations 9 and 10 to be:

$$PV_{water} = \frac{S_w - S_{wc}}{(1-S_{wc}-S_{orw})S_{ew}} \qquad (11)$$

And

$$PV_{gas} = \frac{S_g}{(1-S_{wc}-S_{org})S_{eg}} \qquad (12)$$

This method which can be used to predict future fluid contacts based on predicted water/gas influx is an economic alternative to the pulsed neutron logs and the 4D-seismic methods. However, it is plagued with sloppiness in its accuracy. Because of the limitations of the material balance concept, it is limited to a fairly homogeneous sand body as well as high mobility ratio flow scenarios. Presence of intra-reservoir faults and baffles will also increase the error in the results of this method.

The accuracy of the pore volume versus depth concept also depends on the number of data points available. The higher the number of pore volume versus depth data points, the better prediction of the fluid contacts because the need for interpolation and extrapolation is minimized, as more depths and corresponding pore volumes are captured.

To improve on the accuracy of the material balance, a method of calibrating the model has been suggested.

CALIBRATION METHOD

This is based on the 'tuning' of the sweep efficiency of the material balance model. The vertical sweep efficiency is the percentage of the vertical section of the pay zone that is swept by the displacing fluid. It generally depends on

- Vertical homogeneity
- Degree of gravity segregation
- Fluid mobilities

Heterogeneity in reservoirs will always cause non-uniform sweep efficiency across the reservoir system. Usually, the material balance models assume a 100% sweep by the gas cap and the underlying aquifer. In trying to replicate the flow scenario in the reservoir, and because the sweep efficiency is strongly related to fluid contact movements, alterations of the sweep efficiencies (S_{ew} and S_{eg}) from the ideal state of 100% can be made so as to boost the accuracy of the reservoir models in predicting the fluid contacts.

To perform this calibration, pulsed neutron generated fluid contact is required. With the fluid contact determined by the pulsed neutron logs, the tuning of the model's sweep efficiency can be done until a good match is obtained. When a match is obtained at a given sweep efficiency, such model can be described as calibrated and can be used to predict future fluid contacts.

VALIDATION OF CALIBRATION: NIGER DELTA FIELD CASE STUDY

To validate this calibration concept, a reservoir, D1 in Block B of a shallow offshore Niger Delta field will be used as a case study. The D1 reservoir was discovered in 1990 by well 01, with five other development wells drilled in the next three years. The original fluid contacts as shown in Figure 1 were 8672 feet (gas-oil contact) and 8777 feet (oil-water contact). A material balance model was built for this reservoir using the 238 pore volume versus depth data points, initial rock and fluid properties, and the production data. Furthermore, with the available pore volume versus depth data obtained for this field, the fluid contacts were predicted for the next ten years. In 2000 (after 10 years of production), a pulsed neutron log campaign was launched in the reservoir to ascertain the positions of the fluid contacts. Interpretation of these logs using a petrophysical evaluation tool showed movements in the fluid contacts as described in table 1.

Table 1: Uncalibrated material balance predicted contact vs. contacts generated from C/O logs @ year 2000

MBAL Prediction without calibration		
	GOC (ft)	OWC (ft)
From Logs	8690	8756
From MBAL	8673	8716

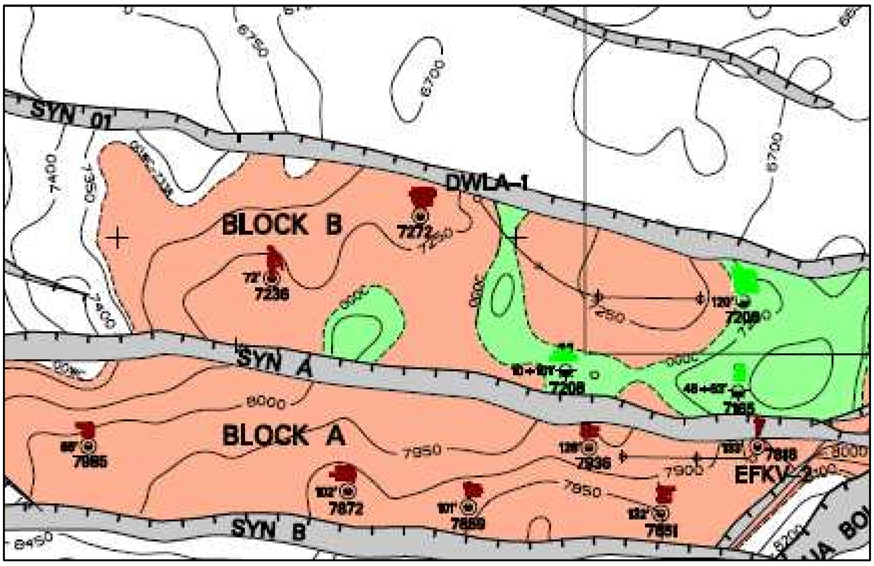


Figure 3: Top structural map of Field X showing completed wells in Block B

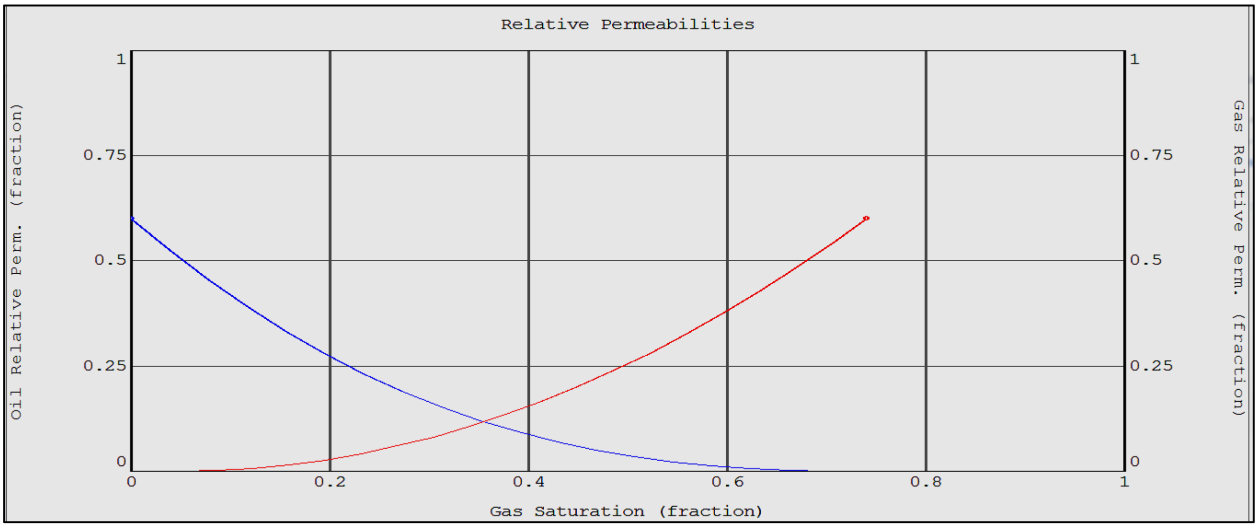


Fig 4: Oil and gas relative permeability vs. S_g plot for D1 fluid

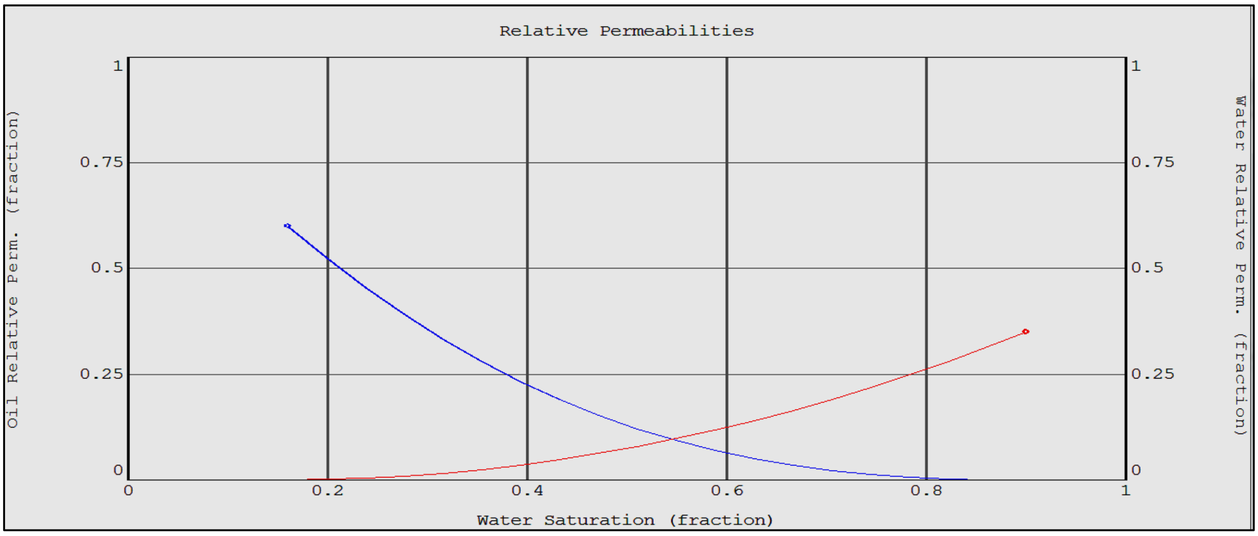


Figure 5: Oil and gas relative permeability plot vs. S_w plot for D1 fluid

Table 2: Corey relative permeability data for D1 reservoir obtained after fractional water and gas matching

	Residual Sat	**End Point**	**Exponent**
Krw	0.16	0.233386	1.82647
Kro	0.1	0.8	17.2441
Krg	0.05	0.0110067	1.39629

Comparing these log-derived fluid contact levels with the material balance predicted contact movements revealed some discrepancies of about 17-feet difference in gas-oil contact and 40-feet difference in oil-water contact. To match the material balance model with the logs, the reservoir was calibrated by tuning the sweep efficiencies using Petroleum Expert's IPM MBAL Suite until it matched the OWC and GOC gotten from the pulsed neutron logs. The final water and gas sweep efficiencies that achieved the match were 91% and 97% respectively. With the calibrated model, a forecast of the future fluid contacts was performed.

To validate the calibration process, there was need to compare the calibrated model's prediction with another carbon-oxygen log. After about another ten years of production, another pulsed neutron log campaign was carried out in the D1 reservoir and the interpreted logs were obtained for the same reservoir.

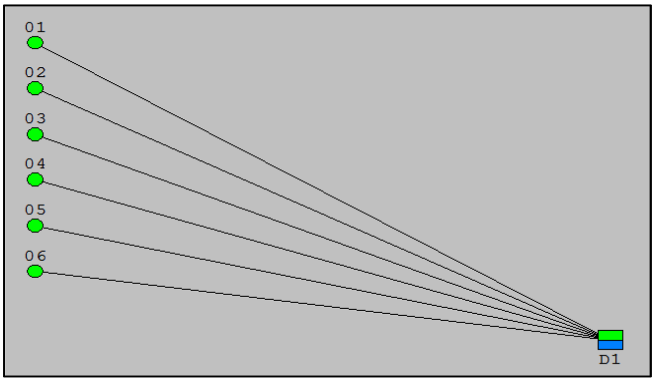
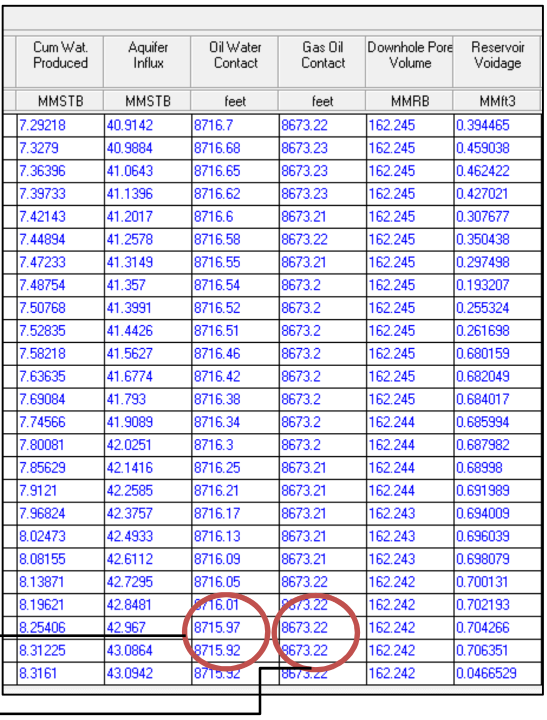


Fig 6: Material Balance model showing reservoir and producing wells



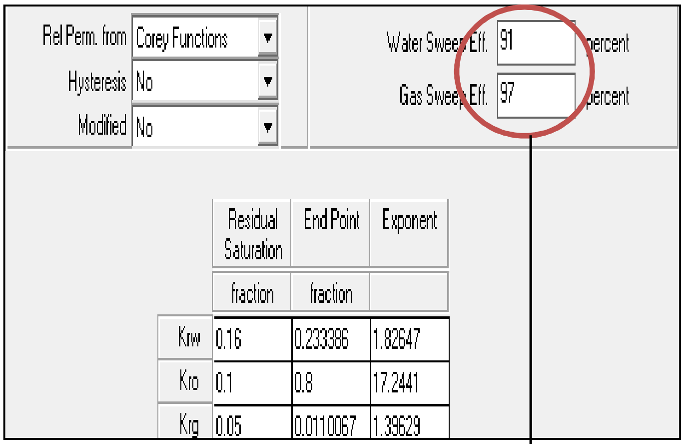
Cum Wat. Produced	Aquifer Influx	Oil Water Contact	Gas Oil Contact	Downhole Pore Volume	Reservoir Voidage
MMSTB	MMSTB	feet	feet	MMRB	MMft3
7.29218	40.9142	8716.7	8673.22	162.245	0.394465
7.3279	40.9884	8716.68	8673.23	162.245	0.459038
7.36396	41.0643	8716.65	8673.23	162.245	0.462422
7.39733	41.1396	8716.62	8673.23	162.245	0.427021
7.42143	41.2017	8716.6	8673.21	162.245	0.307677
7.44894	41.2578	8716.58	8673.22	162.245	0.350438
7.47233	41.3149	8716.55	8673.21	162.245	0.297498
7.48754	41.357	8716.54	8673.2	162.245	0.193207
7.50768	41.3991	8716.52	8673.2	162.245	0.255324
7.52835	41.4426	8716.51	8673.2	162.245	0.261698
7.58218	41.5627	8716.46	8673.2	162.245	0.680159
7.63635	41.6774	8716.42	8673.2	162.245	0.682049
7.69084	41.793	8716.38	8673.2	162.245	0.684017
7.74566	41.9089	8716.34	8673.2	162.244	0.685994
7.80081	42.0251	8716.3	8673.2	162.244	0.687982
7.85629	42.1416	8716.25	8673.21	162.244	0.68998
7.9121	42.2585	8716.21	8673.21	162.244	0.691989
7.96824	42.3757	8716.17	8673.21	162.243	0.694009
8.02473	42.4933	8716.13	8673.21	162.243	0.696039
8.08155	42.6112	8716.09	8673.21	162.243	0.698079
8.13871	42.7295	8716.05	8673.22	162.242	0.700131
8.19621	42.8481	8716.01	8673.22	162.242	0.702193
8.25406	42.967	8715.97	8673.22	162.242	0.704266
8.31225	43.0864	8715.92	8673.22	162.242	0.706351
8.3161	43.0942	8715.92	8673.22	162.242	0.0466529

Predicted oil water contact with uncalibrated model showing OWC of 8716 ft

Predicted gas oil contact with uncalibrated model showing GOC of 8673 ft

Table 3: Some of the 238 Pore Volume VS Depth data

Pore Volume (fraction)	TVD (feet)
-1	8650
-0.969709	8675
-0.730507	8700
0	8705
0.333509	8715
0.315339	8733
0.75003	8750
1	8770



Rel Perm. from Corey Functions

Hysteresis No

Modified No

Water Sweep Eff. 91 percent

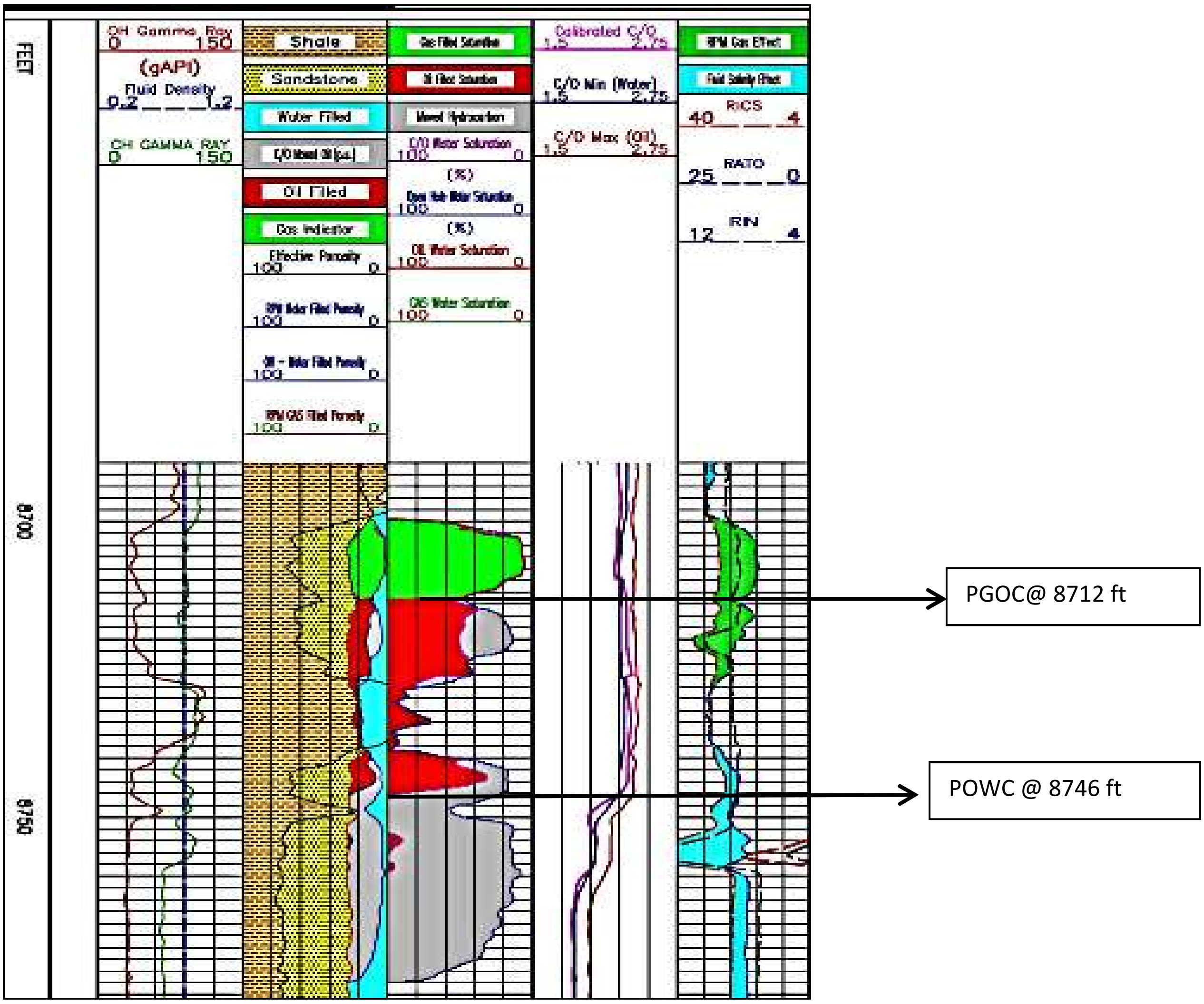
Gas Sweep Eff. 97 percent

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.16	0.233386	1.82647
Kro	0.1	0.8	17.2441
Krg	0.05	0.0110067	1.39629

Calibration of the water and gas sweep efficiency to match the fluid contacts

Table 4: Calibrated material balance predicted contact vs. contacts generated from C/O logs @ year 2010

Mbal Prediction after calibration		
	GOC (ft)	OWC (ft)
From Logs	8710.14	8745.86
From MBAL	8712	8746



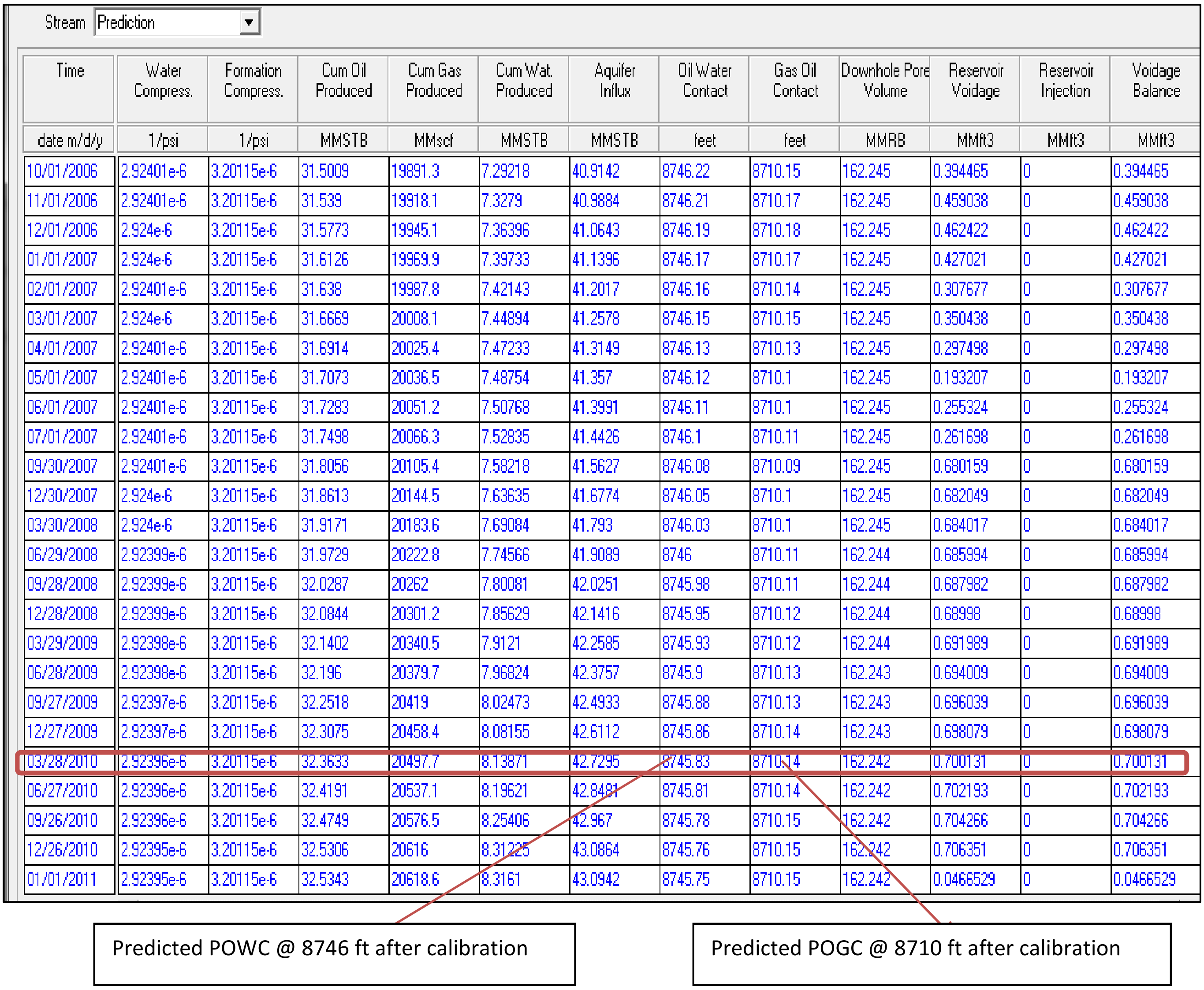
PGOC@ 8712 ft

POWC @ 8746 ft

Fig 7: C/O log showing PGOC and POWC as @ 2010

From the interpreted logs, the fluids contacts were 8712 ft (gas-oil contact) and 8746 ft (oil-water contact) respectively, while those from the calibrated material balance model was 8710.14 ft and 8745.86 ft for the gas-oil and oil-water contact respectively.

The result of the interpretation showed good correspondence between the fluid contact predicted by the calibrated model and the log derived fluid contact as shown in Table 4, thus validating the calibration process.



Time	Water Compress.	Formation Compress.	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Aquifer Influx	Oil Water Contact	Gas Oil Contact	Downhole Pore Volume	Reservoir Voidage	Reservoir Injection	Voidage Balance
date m/d/y	1/psi	1/psi	MMSTB	MMscf	MMSTB	MMSTB	feet	feet	MMRB	MMft3	MMft3	MMft3
10/01/2006	2.92401e-6	3.20115e-6	31.5009	19891.3	7.29218	40.9142	8746.22	8710.15	162.245	0.394465	0	0.394465
11/01/2006	2.92401e-6	3.20115e-6	31.539	19918.1	7.3279	40.9884	8746.21	8710.17	162.245	0.459038	0	0.459038
12/01/2006	2.924e-6	3.20115e-6	31.5773	19945.1	7.36396	41.0643	8746.19	8710.18	162.245	0.462422	0	0.462422
01/01/2007	2.924e-6	3.20115e-6	31.6126	19969.9	7.39733	41.1396	8746.17	8710.17	162.245	0.427021	0	0.427021
02/01/2007	2.92401e-6	3.20115e-6	31.638	19987.8	7.42143	41.2017	8746.16	8710.14	162.245	0.307677	0	0.307677
03/01/2007	2.924e-6	3.20115e-6	31.6669	20008.1	7.44894	41.2578	8746.15	8710.15	162.245	0.350438	0	0.350438
04/01/2007	2.92401e-6	3.20115e-6	31.6914	20025.4	7.47233	41.3149	8746.13	8710.13	162.245	0.297498	0	0.297498
05/01/2007	2.92401e-6	3.20115e-6	31.7073	20036.5	7.48754	41.357	8746.12	8710.1	162.245	0.193207	0	0.193207
06/01/2007	2.92401e-6	3.20115e-6	31.7283	20051.2	7.50768	41.3991	8746.11	8710.1	162.245	0.255324	0	0.255324
07/01/2007	2.92401e-6	3.20115e-6	31.7498	20066.3	7.52835	41.4426	8746.1	8710.11	162.245	0.261698	0	0.261698
09/30/2007	2.92401e-6	3.20115e-6	31.8056	20105.4	7.58218	41.5627	8746.08	8710.09	162.245	0.680159	0	0.680159
12/30/2007	2.924e-6	3.20115e-6	31.8613	20144.5	7.63635	41.6774	8746.05	8710.1	162.245	0.682049	0	0.682049
03/30/2008	2.924e-6	3.20115e-6	31.9171	20183.6	7.69084	41.793	8746.03	8710.1	162.245	0.684017	0	0.684017
06/29/2008	2.92399e-6	3.20115e-6	31.9729	20222.8	7.74566	41.9089	8746	8710.11	162.244	0.685994	0	0.685994
09/28/2008	2.92399e-6	3.20115e-6	32.0287	20262	7.80081	42.0251	8745.98	8710.11	162.244	0.687982	0	0.687982
12/28/2008	2.92399e-6	3.20115e-6	32.0844	20301.2	7.85629	42.1416	8745.95	8710.12	162.244	0.68998	0	0.68998
03/29/2009	2.92398e-6	3.20115e-6	32.1402	20340.5	7.9121	42.2585	8745.93	8710.12	162.244	0.691989	0	0.691989
06/28/2009	2.92398e-6	3.20115e-6	32.196	20379.7	7.96824	42.3757	8745.9	8710.13	162.243	0.694009	0	0.694009
09/27/2009	2.92397e-6	3.20115e-6	32.2518	20419	8.02473	42.4933	8745.88	8710.13	162.243	0.696039	0	0.696039
12/27/2009	2.92397e-6	3.20115e-6	32.3075	20458.4	8.08155	42.6112	8745.86	8710.14	162.243	0.698079	0	0.698079
03/28/2010	2.92396e-6	3.20115e-6	32.3633	20497.7	8.13871	42.7295	8745.83	8710.14	162.242	0.700131	0	0.700131
06/27/2010	2.92396e-6	3.20115e-6	32.4191	20537.1	8.19621	42.8481	8745.81	8710.14	162.242	0.702193	0	0.702193
09/26/2010	2.92396e-6	3.20115e-6	32.4749	20576.5	8.25406	42.967	8745.78	8710.15	162.242	0.704266	0	0.704266
12/26/2010	2.92395e-6	3.20115e-6	32.5306	20616	8.31225	43.0864	8745.76	8710.15	162.242	0.706351	0	0.706351
01/01/2011	2.92395e-6	3.20115e-6	32.5343	20618.6	8.3161	43.0942	8745.75	8710.15	162.242	0.0466529	0	0.0466529

Predicted POWC @ 8746 ft after calibration

Predicted POGC @ 8710 ft after calibration

Furthermore, a dynamic model of the D1 reservoir was also used to predict the fluid contact of the reservoir in the year 2015 under the assumptions that the operating conditions of the reservoir production remains constant. Also, the calibrated material balance model was also used to predict the fluid contact at the same year (2015), and the results showed that both methods yielded a fair match as shown in table 6.

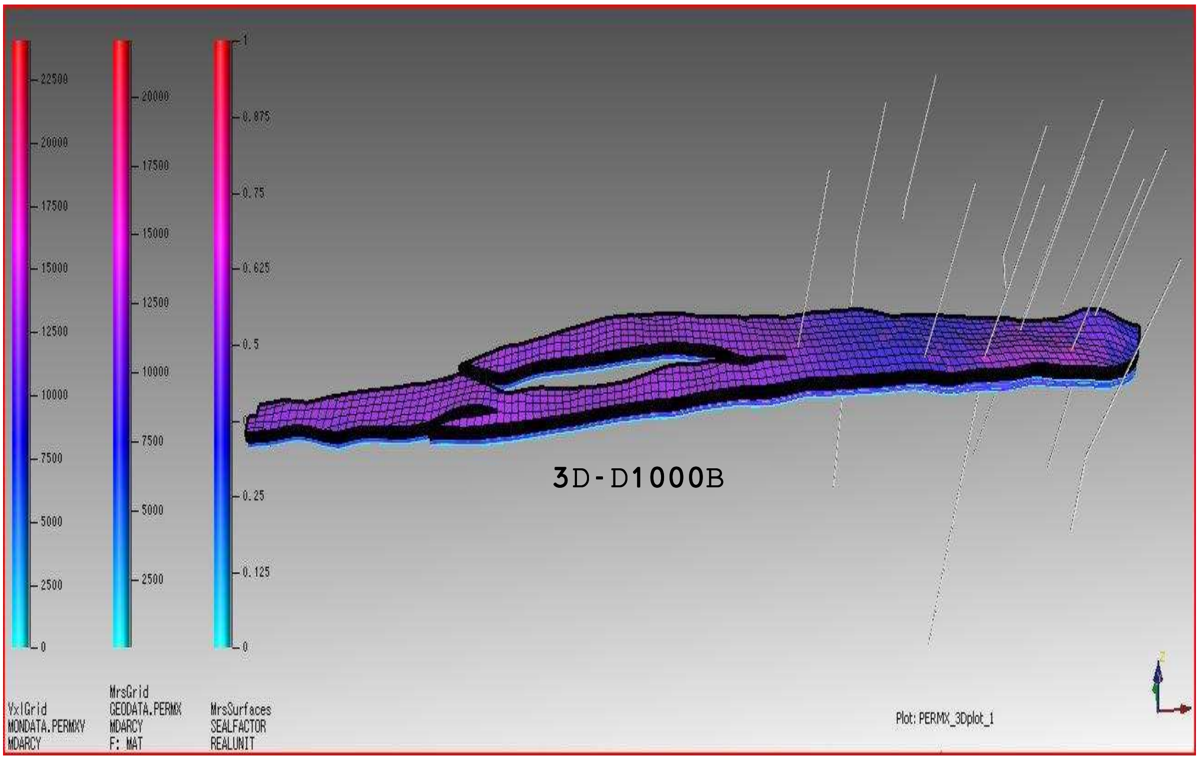


Figure 8: 3D model of reservoir used for prediction of fluid contact to 2015

Table 5: Statistical errors (Absolute Deviation and Average Relative Error) in material balance predictions

GAS-OIL CONTACT			
Year	***2000***	***2010***	***2015***
AD*	17	2	1.9
ARE (%)**	0.195	0.023	0.022

OIL -WATER CONTACT			
Year	***2000***	***2010***	***2015***
AD*	40	0.14	1.24
ARE (%)**	0.457	0.0016	0.014

Table 6: Material balance versus Simulator results at 2015

Mbal versus Simulator @ 2015		
	GOC (ft)	OWC (ft)
From Simulator	8719.3	8741.11
From MBAL	8721.2	8739.87

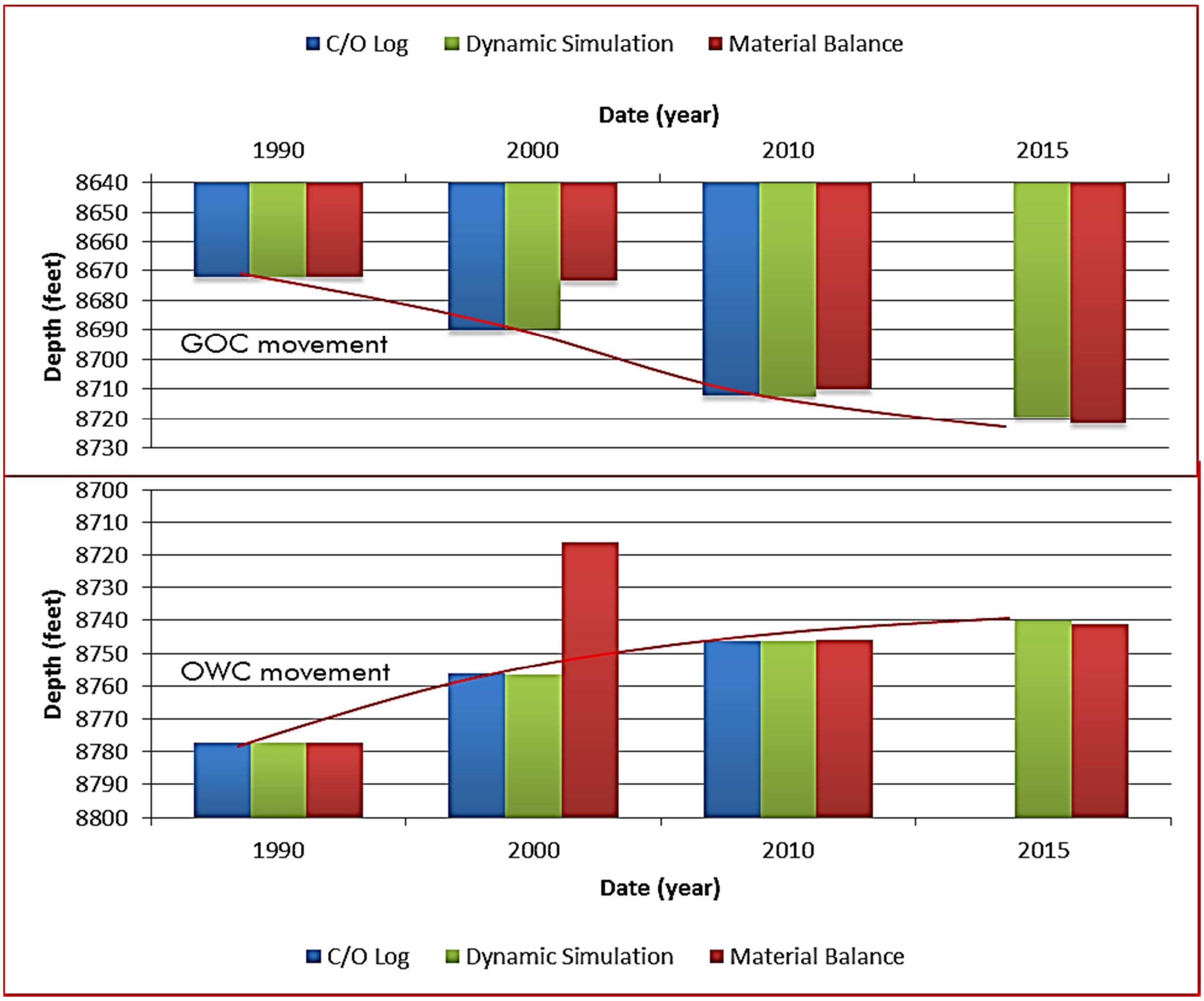


Figure 9: Graphical movement of fluid contacts over the years using the different methods

CONCLUSION AND RECOMMENDATION

The use of PNS and PNC logs are the traditional methods used to analyse the fluid contact movements in the reservoir. Due to the expensive nature of this method, an alternative and less expensive method was presented based on material balance analysis.

A case study was used to validate the theory proposed and a good match was obtained showing that a calibrated material balance can be used to predict fluid contacts to reasonable accuracy. This method is however limited to high mobility ratio and homogeneous reservoirs. Material balance assumptions also apply to the limitation of this method.

Generally, it is advised that this method be used as a complement and not a complete replacement of the pulsed neutron techniques. Discrepancies within the predictions of the models can help in understanding the reservoir better and could yet help provide answers to complex reservoir uncertainties.

ABBREVIATIONS

B_g = Gas formation volume factor (rbl/stb)

B_o = Oil formation volume factor (rbl/stb)

B_{oi} = Initial Oil formation volume factor (rbl/stb)

C/O = Carbon/Oxygen
c.u = Capture Units

$m =$ Ratio of initial gas-cap volume to initial reservoir oil volume (bbl/bbl)
$N_p =$ Cumulative Oil Produced (stb)
$N =$ Original Oil in Place (stb)
PGOC = Present Gas Oil Contact
PNC = Pulsed Neutron Capture
PNS = Pulsed Neutron Spectroscopy
POWC = Present Oil Water Contact.
PV = Pore Volume
$S_o =$ Oil Saturation
$S_g =$ Gas Saturation
$S_w =$ Water Saturation
$S_{wc} =$ Connate Water Saturation
Sorg = Residual oil saturation with respect to gas
Sorw = Residual Oil saturation with respect to water
Sorx = Residual Oil saturation with respect to fluid x.
$R_{si} =$ Initial gas-oil ratio (scf/stb)
$R_p =$ Cummulative produced gas-oil ratio (scf/stb)
$R_s =$ Solution gas-oil ratio (scf/stb)
$W_e =$ Cummulative Aquifer Influx (bbls)
$W_p =$ Cummulative Water Produced (bbls)
$V =$ Reservoir Volume (acre.ft)
$P_i =$ Initial pressure of the aquifer (psi)
$W_{ei} =$ Maximum possible water influx (bbl)

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