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New Approach to tackle LRLC Reservoirs of Changmaigaon

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Abstract

Changmaigaon field is located in North Assam Shelf of Assam and Assam Arakan basin. Uncertainties caused by fluid distribution and low resistivity – low contrast anomalies pose major challenges for development of the field. Tipam reservoir TS-5A, the major oil producer of Changmaigaon field is the typical example of Low Resistivity Low Contrast anomaly where the problem is to such an extent that resistivity in oil producing zones is at places even less than in water producing zones. Efforts using conventional approach have not given meaningful results for identification and evaluation of hydrocarbon zones from logs.

The main reasons for low resistivity - reverse resistivity contrast between oil and water bearing zones are thought to be the presence of grain coating authigenic dispersed clays, fresh water environment and metamorphic rock fragments, chloritized mica and heavy iron oxide minerals at places based on studies of core samples, SWC's and log motifs.

In the study by CEWELL Institute of ONGC, two techniques are used for saturation computation: in high salinity (KCl) mud systems, the SP log which is nothing but a membrane potential log only and is representative of CEC/Qv is used to provide correction factor in Sw. For non-KCl (normal) mud systems, a vintage Rxo/Rt vs SP quantification scheme is used to compute Sw. The paper discusses case histories and demonstrates how integration of SP and resistivity logs provides reasonable answers in many LRLC cases of Changmaigaon where conventional methods fail completely.

Introduction

Tipam reservoir TS-5A, the main oil producer of Changmaigaon field (Fig-1) is the typical example of Low Resistivity - Low Contrast anomaly. The problem is to such an extent that at places resistivity in oil producing zones is even less than that in water producing zone. For instance, the well #E, drilled over 30 years ago, has produced nearly clean oil from the interval 'XX' (top portion of TS-5A sand) (Fig-2).

An earlier study (Ref-1) has laid the ground for further work outlined in this paper. In the referred study, methods to identify the OWC using a) Rxo/Rt vs. SP overlay, b) SP and MSFL logs in high salinity KCl mud were evolved and validated against known hydrocarbon and water bearing zones in TS-4 & TS-5. Further, an effective methodology for realistic estimation of water saturation through integration of SP and resistivity logs in wells drilled with high salinity KCl-PHPA mud system was also formulated. Later a scheme for saturation determination by Rxo/Rt vs SP overlay was also implemented through a simple computer program.

In the present work, the mentioned two techniques have been applied for extensive processing of twenty three wells, eleven of which have been drilled with high-salinity KCl-PHPA muds. To facilitate the computations, a GUI based versatile software for Windows PC named 'LRLCewell' has been developed.

Discussion of challenges in computation of Sw in low resistivity contrast sands:

Commonly used shaly sand saturation equations attempt to compensate for shale contribution in the rock conductivity according to its volumetric proportion (V_{shale}) and resistivity of nearby shale beds. These are generally effective in situations where the assumptions that clay minerals present in the reservoir section are same as in the nearby shale beds, and that they have the same properties holds reasonably correct. They do not address the type and distribution of clay minerals and so become inadequate when clay minerals present in the reservoir rock are not same as in nearby shale (in case of authigenic grain coating clays). In real situations, usually shaly sands contain laminated as well as dispersed clay forms. Another major shortcoming of the V_{shale} models is the use of non-electrical measurements such as GR, Rhob, Nphi, Pe, Dt etc. ('clay indicators') to compensate the electrical measurement of rock resistivity. Thus, though the Indonesian equation which is generally suitable for fresh water environment, fails to compute realistic water saturation in reservoirs like TS-5A of Changmaigaon area.

The 'Waxman-Smits', 'Dual Water', 'Juhasz' etc. saturation models generally used for dispersed clays are based essentially on the concept of ionic double layer being present on the sand grains and the cationic exchange between negatively charged clay surfaces and pore space brine solution. Field implementation of these models can be really effective if continuous measurement of Qv is available through extensive core analyses or log measurement. These models are also unable to solve the low-contrast/reverse-contrast problem in TS-5A sand of Changmaigaon wells.

Since the electrical manifestation of non-Archie rocks is the net result of effects of rock & pore structure, distribution of clays & mineral assemblage and distribution of fluid phases, the realistic evaluation of such complex reservoirs deposited in fresh water environment and containing authigenic as well as allogenic clays, conducting heavy minerals, metamorphic rock fragments of conducting nature, could be better feasible if an additional measurement which is affected by these factors in a similar manner as resistivity be used. A complementary measurement such as SP log recorded in high salinity KCl-PHPA can be used to provide a suitable correction to resistivity of shaly sands as demonstrated here.

A. Role of SP Log in High Salinity KCl-PHPA mud:

SP is the result of several electromotive forces: shale membrane potential E_m, liquid-junction potential E_j, and electro-kinetic potential E_k.

$$E = E_c + E_k = E_m + E_{lj} + E_k$$ ------(Eqn. 1)

In KCl-PHPA high salinity mud system, where the NaCl is largely replaced by KCl, the SP log is nothing but a membrane potential log only, with the E_{lj} and E_k components becoming negligibly small.

B. Effect of high salinity KCl mud on Electro-kinetic Potential E_k

$$E_K = \frac{\zeta.D.\Delta P.R_{mf}}{4\pi\mu} \approx 0$$ ------(Eqn. 2)

- In Changmaigaon field, R_{mf} in KCl based mud (0.05-0.2 Ohm-m.) is about 20~40 times less than in conventional NaCl based muds (1.5 to 2.5 Ohm-m) because salinity of most KCl mud formulations is usually more than 50 Kppm.
- Zeta potential 'ζ' and dielectric constant 'D' also reduce with increase in salinity.
- PHPA polymer increases the viscosity μ of the mud filtrate. (ΔP is the pressure difference between borehole and formation)
- Therefore E_k is negligible due to very low R_{mf}, lower zeta potential & dielectric constant and high viscosity of mud filtrate of KCl-PHPA muds.

C. Effect of high salinity KCl mud on Electro-chemical Potential E_c

$$E_c = E_m + E_{lj} = -K * \frac{R_{mf}}{R_w} \qquad E_{lj} \approx -0.17 * K * \log\frac{R_{mf}}{R_w}$$ ------(3)

where K is a temperature dependent constant

- The transport number of K+ ion (0.496) and Cl- ion (0.504) are approximately equal because both the ions attain the same electronic configuration as that of Argon atom.

- When two KCl solutions of different salinities make an interface, no liquid junction potential develops because the Potassium ion K^+ and Chloride ion Cl^- carry equal and opposite electrical current.

- Since diffusion of ions always takes place from solutions of higher to lower salinity, even if formation water is NaCl and mud filtrate is KCl, very little liquid junction potential is generated due to nearly equal ionic mobilities of K^+ & Cl^- ions.

- The value of 'K' (eqn-3) for KCl (0.1 mV) is 127 times less as compared to NaCl (12.7 mV).
- Therefore practically no liquid junction potential develops in KCl-PHPA mud systems.

Thus, in high salinity mud filtrate, the SP log is nothing but a membrane potential log.

$$E \approx E_m$$

D. Effect of Hydrocarbons on SP Log in KCl mud:

- The presence of hydrocarbons increases the effect of CEC & Qv of the clays which in turn reduces resistivity contrast between hydrocarbon and water bearing zones. (Ref.-5, 7, 8, 12).
- Since E_m is the dominant component of SP development, the high salinity contrast between KCl mud filtrate and connate water enhances the overall amplitude of SP log making it more sensitive to the presence of hydrocarbons.
- In a clean sand, there is little difference in SP value against oil and water bearing sections, while the effect is more pronounced in case of shaly sands (Ref.-5). Further, the changes in SP due to shaliness are also more pronounced against oil bearing section than water bearing ones.
- Thus, hydrocarbon bearing layers appear to be shalier than their water bearing counterparts with same amount of clays.
- Hence, in KCl mud situation and low-moderate shaliness, the SP log responds to the changes in hydrocarbon saturation. (Ref.-15).
- Since the resistivity of partially saturated porous media depends upon all the above mentioned factors, the compensation for apparent low-resistivity-low-contrast can be applied through SP log in KCl mud environment for realistic evaluation.
- This reasoning forms the basis of the technique demonstrated here.

Methodology :

- Standardized mineralogical model and matrix parameters based on cross-plots of various log parameters and available core & lab data and the Archie's 'a', 'm', 'n' parameters from lab data compilation used for processing.
- Identification of major clay types from NGS log cross-plots and lab reports for use in mineralogical model: Montmorillonite & Kaolinite with minor Illite & Chlorite.
- A two-step approach has been adopted for the two different types of mud conditions, ie. Normal mud and high salinity KCl mud.
- In the first step, the formation lithology volumes have been computed using a multi-mineral inverse modeling software.

1. For high-salinity (KCl) mud systems:

- Normalization of SP log for clay volume computed without use of SP in ELANPlus, using the relation:

  $$SPN = \frac{SP}{1 - V_{cl}} \quad \text{------------------(4)}$$

  where SPN is the SP amplitude obtained after making shale base line zero. This removes the volume weighted effect of all clay types, because the volume weighted clay compensation has been incorporated through Indonesian equation and only the effect of hydrocarbons on Qv remains.

- Estimation of membrane potential of perfect shale membrane and estimation of membrane potential of 100% water bearing zone ($\Delta U_{Sw=1}$) from normalized SPN log. In practice, this is done graphically from the SPN curve.
- Use of Normalized SP to compensate for reduction of resistivity due to effect of enhancement of Qv in hydrocarbon zones.

- In second step, the SP log (effectively, the membrane potential log representative of Qv/CEC) has been used to add a correction factor in computing Sw.

2. For normal mud systems:

- The Pseudo Static SP (PSP) of water bearing shaly sands is related to R_{xo}/R_t ratio in a similar way as Static SP (SSP) of clean water sands is related to R_{mf}/R_w ratio.

SP_{log} = $-K .\log R_{mf}/R_w$ ------------------------- (5)

It can be shown that S_w can be computed as:

$S_w \approx 10^{(-\Delta SP/0.8.n^* K)}$ ---------------------- (6)

The steps involved are :

- Computation of ΔSP log as a measure of hydrocarbon saturation.
- Normalization of ΔSP against water bearing zone, ie. setting ΔSP=0 against the water zone.
- Computation of Sw using the Normalized ΔSP.

- The two methodologies for high-salinity and normal mud systems have been implemented through custom developed Windows PC computer program named 'LRLCewell'.

Results

- Twenty three wells have been processed using the techniques discussed. To illustrate the effectiveness, one case each of non-KCl mud and KCl mud is described below.
- Fig-3 shows the log processing of well #M which was drilled with normal mud. The resistivity against top part ('zone-1') of the TS-5A reservoir is about 6 ohm-m and it gradually rises to about 9 ohm-m against water-bearing part ('zone-2'). Conventional log processing would give 100% Sw value against 'zone-1' assuming that 'zone-2' is water bearing. The assumption that 'zone-2' is water bearing is reasonable as this demarcation ('OWC') is visible on logs and the level is fairly consistent in the vicinity of the field. With the new technique discussed above, water saturation computed against 'zone-1' is ~50-55%. The zone produced oil@43m^3/d with 1% water cut.
- Fig-4 shows the log processing of well #G which was drilled with high salinity KCl-PHPA mud. The resistivity against top part ('zone-1') of the TS-5A reservoir is about 5-7 ohm-m and it gradually rises to about 8-9 ohm-m against water-bearing part ('zone-2'). Conventional log processing would give 100% Sw value against 'zone-1' assuming that 'zone-2' is water bearing. Again the assumption that 'zone-2' is water bearing is reasonable as this demarcation ('OWC') is distinctly visible on logs. Water saturation computed against 'zone-1' is ~30-60%. The zone gave oil@48m^3/d with 21% water cut.
- In the 23 well processed using the new technique, realistic water saturation could be computed for many cases (including sub-layers of TS-4 & TS-5) where the conventional methods failed.

Conclusions

- Integration of SP and resistivity logs through the proposed technique provides reasonable answers in many LRLC cases of Changmaigaon where conventional methods fail completely.
- The main reasons for low resistivity - reverse resistivity contrast between oil and water bearing zones of Tipam TS-4 & 5 of Changmaigaon area are the presence of grain coating authigenic dispersed clays, fresh water environment with presence of metamorphic rock fragments, chloritized mica and heavy iron oxide minerals at places.
- A two-step approach has been adopted for computation of mineral volumes, effective porosity and hydrocarbon saturation in the LRLC zones for the two different types of mud conditions, ie. Normal mud and high salinity KCl mud.
- In the first step, the formation volumes have been computed using multi-mineral software. In second step, Sw for normal muds is computed using quantification scheme of Rxo/Rt vs. SP overlay. For KCl based high salinity mud, the SP log (effectively, the membrane potential log representative of Qv/CEC) has been used to add a correction factor in computing Sw.
- The areas of concern are low or erratic SP anomaly where 100% shale or 100% water levels are difficult to identify, lack of clear-cut water-bearing levels for normalization/calibration and use of shallow resistivity log which may not read true 'Rxo'.

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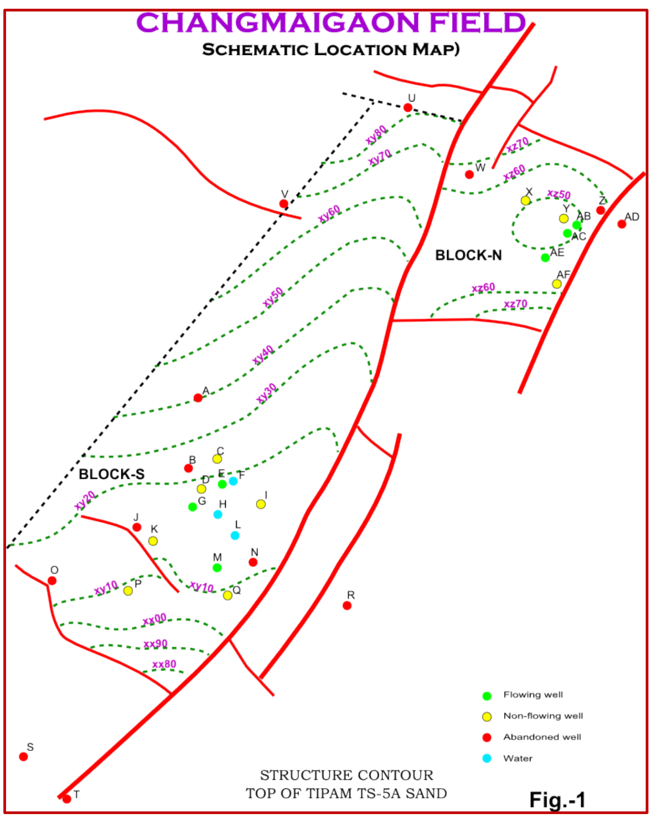


Fig-1: Schematic Location Map of Changmaigaon field

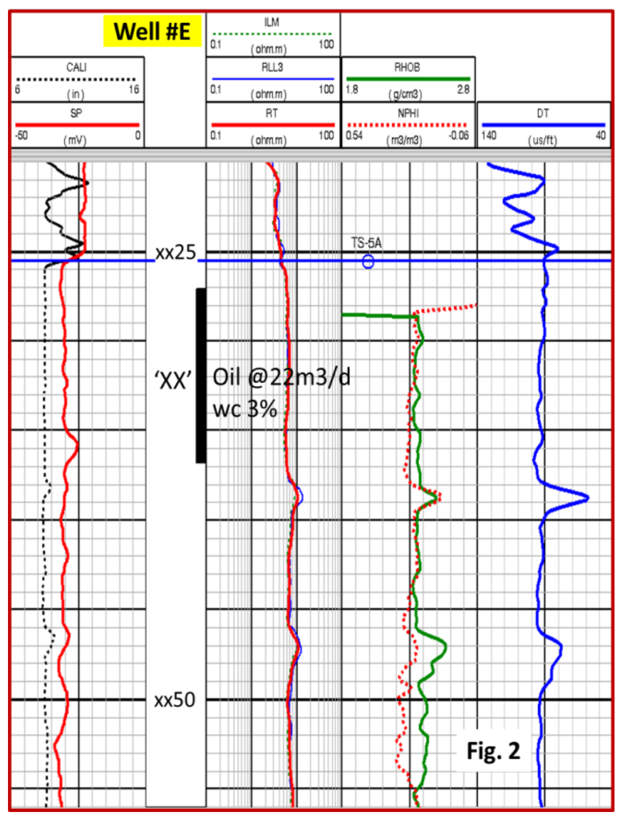
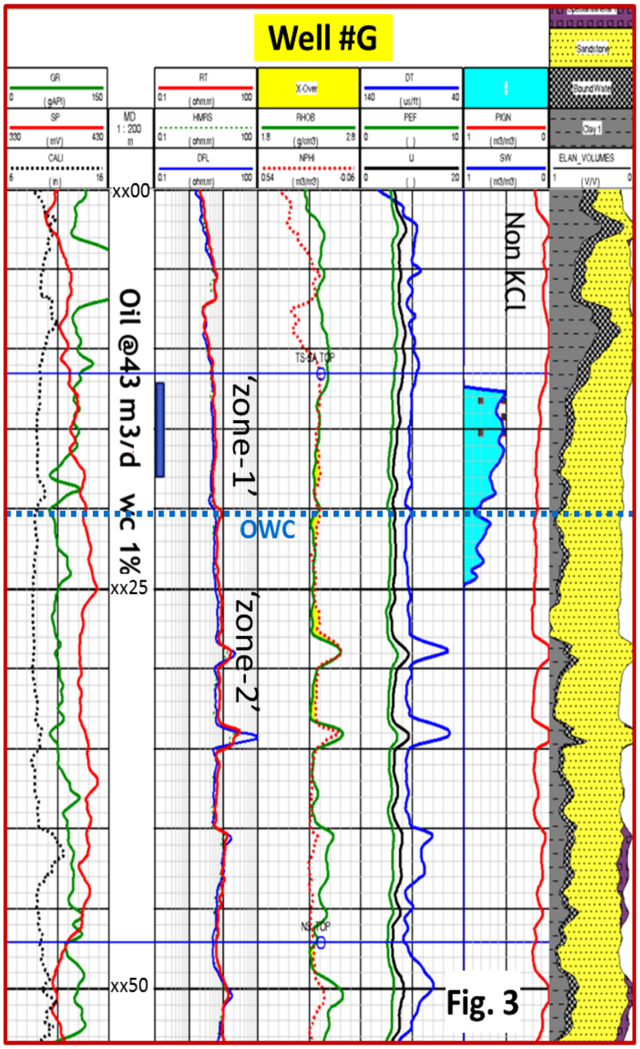


Fig-2: Composite Log of well #E, drilled over 30 years ago, producing nearly clean oil @ 22m^3/d from interval ‘XX’ (top part of TS-5A sand)



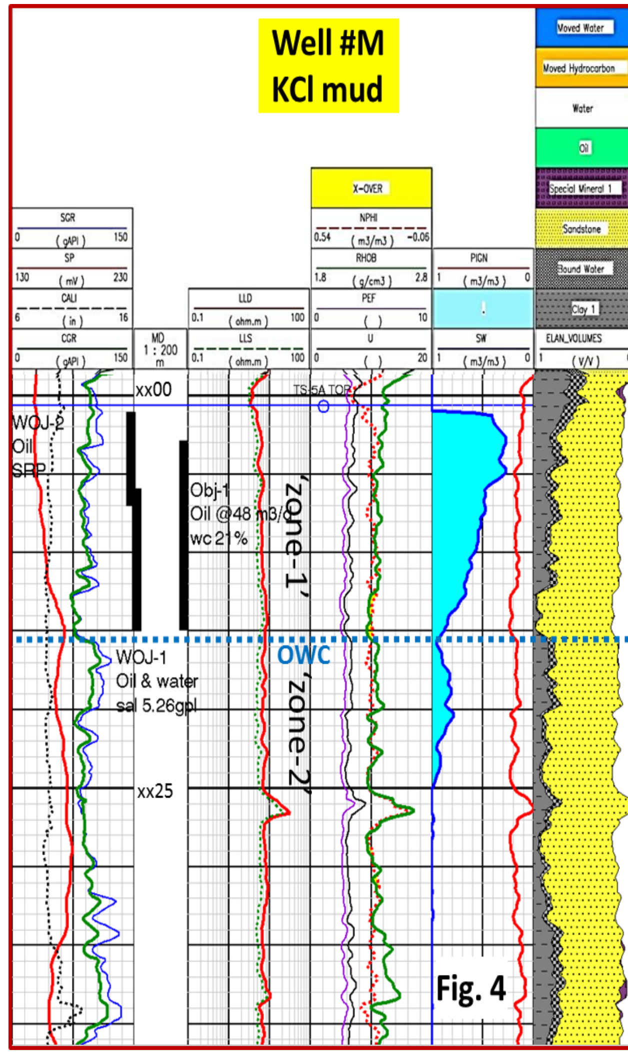


Fig-3: Well #G (drilled with non-KCl mud). Log data processing of LRLC TS-5A sand with new technique is able to compute realistic Sw~50-55%. 'zone-1' produced oil@43m^3/d with 1% water cut.

Fig-4: Well #M (drilled with KCl mud). Log data processing of LRLC TS-5A sand with new technique is able to compute realistic Sw ~30-60%. 'zone-1' produced oil@48m^3/d with 21% water cut.