Enhanced Fluid Characterization for Improved Saturation & Connectivity

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ABSTRACT 1133

Abstract

To accurately determine water / hydrocarbon saturation profile, hydrocarbon typing & reservoir extent/connectivity in real time by acquiring insitu water salinity downhole, hydrocarbon optical density & composition.

The uncertainties present from water salinity values from nearby wells which varies vertically & areal in Archie based fluid saturation may cause inaccurate hydrocarbon presence which affects reservoir hydrocarbon in place. Also, using the optical fluid analyser to identify the reservoir connectivity & hydrocarbon typing is essential for field development planning.

A new method using optical spectroscopy measurements along with induction resistivity measurement to identify hydrocarbon compositions & water salinity more accurately which aids to reconstruction of the petrophysical model to recompute fluid saturation profile accurately. As well, confirming vertical connectivity across the hydrocarbon column and hydrocarbon typing through Reservoir Fluid Geodynamics applications by constructing Flory-Huggins-Zuo equation of state model and identifying asphaltene molecular size from optical density gradient.

The study demonstrates that by using downhole induction measurements for resistivity values aiding to an accurate reconstruction of saturation profile of the petrophysical model in real time which was proven in a development well. This helps in accurately identifying hydrocarbon in place and optimizes the sampling program & fluid identification expectation as well.

The Rw was measured at the bottom of the reservoir from pump out station, after achieving clean-out (negligible contamination) and input in the initial petrophysical model to recompute the fluid saturation which was confirmed by conducting downhole fluid analysis stations.

Similarly, the optical spectroscopy confirms the vertical connectivity though Reservoir Fluid Geodynamics & indicates a compositional gradient in real time in an oil column. This was done by constructing Flory-Huggins-Zuo Equation of State model and identifying asphaltene molecular size from optical density gradient.

The use of both induction resistivity & optical fluid scanner in real time assisted in determination of accurate hydrocarbon in place per unit area & accurate hydrocarbon typing.

This methodology will bring more accurate & reliable results compared to conventional method which has plenty of uncertainties creating inaccurate reservoir evaluation results. Also, will help in optimizing sampling & downhole fluid analysis programs which eventually saves cost & time.

Introduction

Conventional practices of using nearby field salinity or waiting for downhole sampling lab results to determine saturation profile is inefficiently inaccurate as many critical decisions are based on real time evaluation are jeopardized due to lead time consumed for water lab analysis on acquired downhole samples. These decisions can cause unnecessary sampling or downhole fluid analysis (DFA) pumping stations to confirm the accuracy of initial water salinity assumptions by confirming the fractional flow with formation tester.

The study demonstrates that by using downhole induction measurements for resistivity values aiding to an accurate reconstruction of saturation profile of the petrophysical model in real time which was proven in a development well. This helps in accurately identifying hydrocarbon in place and optimizes the sampling program & fluid identification expectation as well.
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Similarly, the optical spectroscopy confirms the vertical connectivity though Reservoir Fluid Geodynamics & indicates a compositional gradient in real time in an oil column. This was done by constructing Flory-Huggins-Zuo Equation of State model and identifying asphaltene molecular size from optical density gradient.

The use of both induction resistivity & optical fluid scanner in real time assisted in determination of accurate hydrocarbon in place per unit area & accurate hydrocarbon typing.
This methodology will bring more accurate & reliable results compared to conventional method which has plenty of uncertainties creating inaccurate reservoir evaluation results. Also, will help in optimizing sampling & downhole fluid analysis programs which eventually saves cost, time & unnecessary CO2 emissions. Furthermore, the application of the RFG from FHZ asphaltene gradient can be utilized for early detection of flow assurance concerns & location prediction.

Methodology, Description & application

1. Reconstruction of Saturation Profiling

Formation water salinity is a key reservoir parameter required in any petrophysical analysis. There are several log-based techniques to derive formation salinity or formation water resistivities, such as the spontaneous potential log (SP) (Doll 1948) or Pickett's plot (G. R. Pickett 1966), which utilizes deep resistivity and porosity. Those techniques, however, depend on the log analyst interpretation. Laboratory analysis of downhole formation water samples is a reliable methodology to calibrate salinity and the petrophysical evaluation. Because the lab analysis can take time, this cannot be used to take

decisions on ongoing logging operations, otherwise it can delay the formation evaluation process. Nevertheless, such uncertainty with salinity will impact the initial reserve estimation & sometimes initial OWC & GWC.
In development field this even becomes more complex as sometimes water injection will change the initial salinity values & the initial constructed saturation profile which will introduce a high uncertainty & will prevent proper understanding of waterfront / sweep efficiency as well.

Formation water salinity is determined by a new induction resistivity cell which has a wide dynamic range with high accuracy and resolution to differentiate small changes in resistivity measurement. The cell is deployed in the flow line of the wireline formation tester module, which performs the measurement as fluid passes through. Unlike electrode-based design, the induction resistivity eliminates the effect of electrode and fluid contact due to the presence of oil or mud droplets coating the electrode. Even in water-based mud environment, small traces of lubricants may affect the electrode-based measurement.
The principle of the induction resistivity measurement is based on two electromagnetic coils, a current generation coil and a current receiver coil. An electrical current is induced into the flowline fluid from the generation coil with a known voltage (Vin). The current induced is proportional to the conductivity of the fluid (inversely proportional to resistivity) which is picked by the receiving coil (I out) and measured as conductivity (Hua Chen et al. 2020).
The Formation water flows through the induction coil in a neutrally wet tube which prevents fouling and ensures minimum impact of the solids present in the mud.
The water resistivity value (Rw) is computed from the reciprocal of conductivity measurement. This is obtained after pumping a significant volume of fluid from the formation to ensure that the water is clean with no impurities from the mud filtrate. This process is done while continuously measuring the rate of resistivity change (water contamination monitoring, WCM) transitioning from water base mud filtrate into pure formation water. The accuracy of the measurement relies heavily on the estimated contamination values, the lower the contamination the more accurate the measurement. Fluid contamination in flow line either from hydrocarbon or mud solids can have big impact on resistivity measurement, therefore achieving lower possible contamination is a key when we derive fluid resistivity later converted to salinity. The cases presented here have negligible amounts of contamination to enhance the quality and accuracy of the measurement.

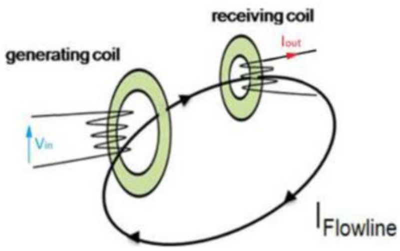


Figure 1

Specification	Value
Temperature	200degC
Pressure	20kpsi / 35kpsi
Resistivity Range	0.01 – 65 Ω.m
Resistivity Accuracy	<+/−5% from 0.01 to 20 Ω.m <+/−10% from 20 to 65 Ω.m (< 170degC)
Resistivity Resolution	<0.001 Ω.m from 0.01 to 5 Ω.m 0.75% of reading from 5 to 65 Ω.m

Table 1- Downhole resistivity cell specifications

In our case, the initial salinity values were assumed to be ~180 kppm which computed some oil saturation in the bottom reservoir section of the Zone A (Figure 2, left Track). These results turned out to be inaccurate after conducting a Down hole Fluid Analysis station & measuring insitu resistivity accurately. This was done by pumping sufficient volume while measuring the rate of change in resistivity & density measurement to confidently assure that salinity values are accurately representing clean formation water (Figure 3). The new salinity values of ~110kppm were plugged in the modified archie's equation to regenerate an accurate saturation profile (Figure 2, right track) that was confirmed later with multiple DFA stations. This was done by confirming water & oil fractions pumped from DFA stations after stabilization (Figure 4, Track 8).

The new corrected saturation profiling results were integrated with other open hole data, DFA stations good quality pressure gradients to confirm an accurate understanding with the reservoirs for further developments studies (Figure 4).

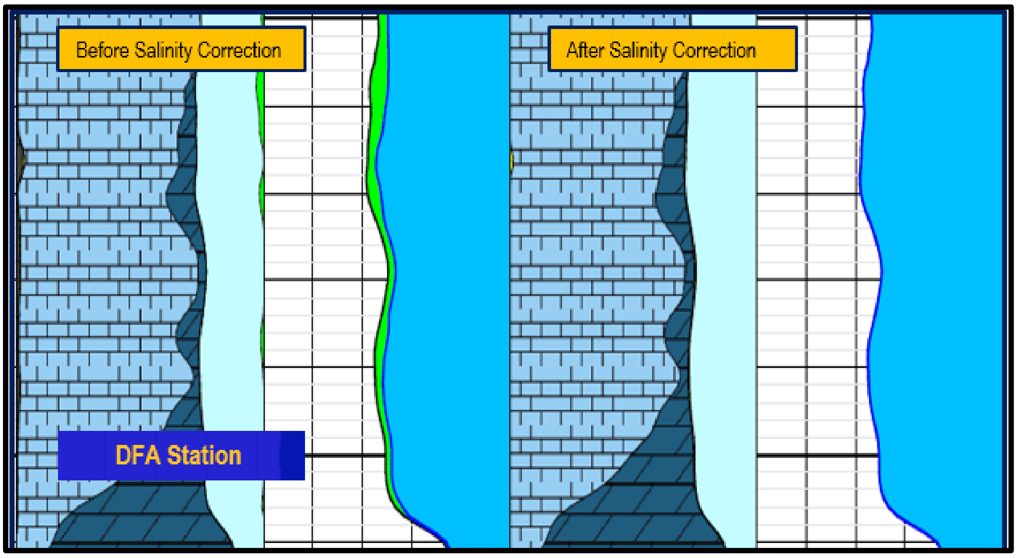
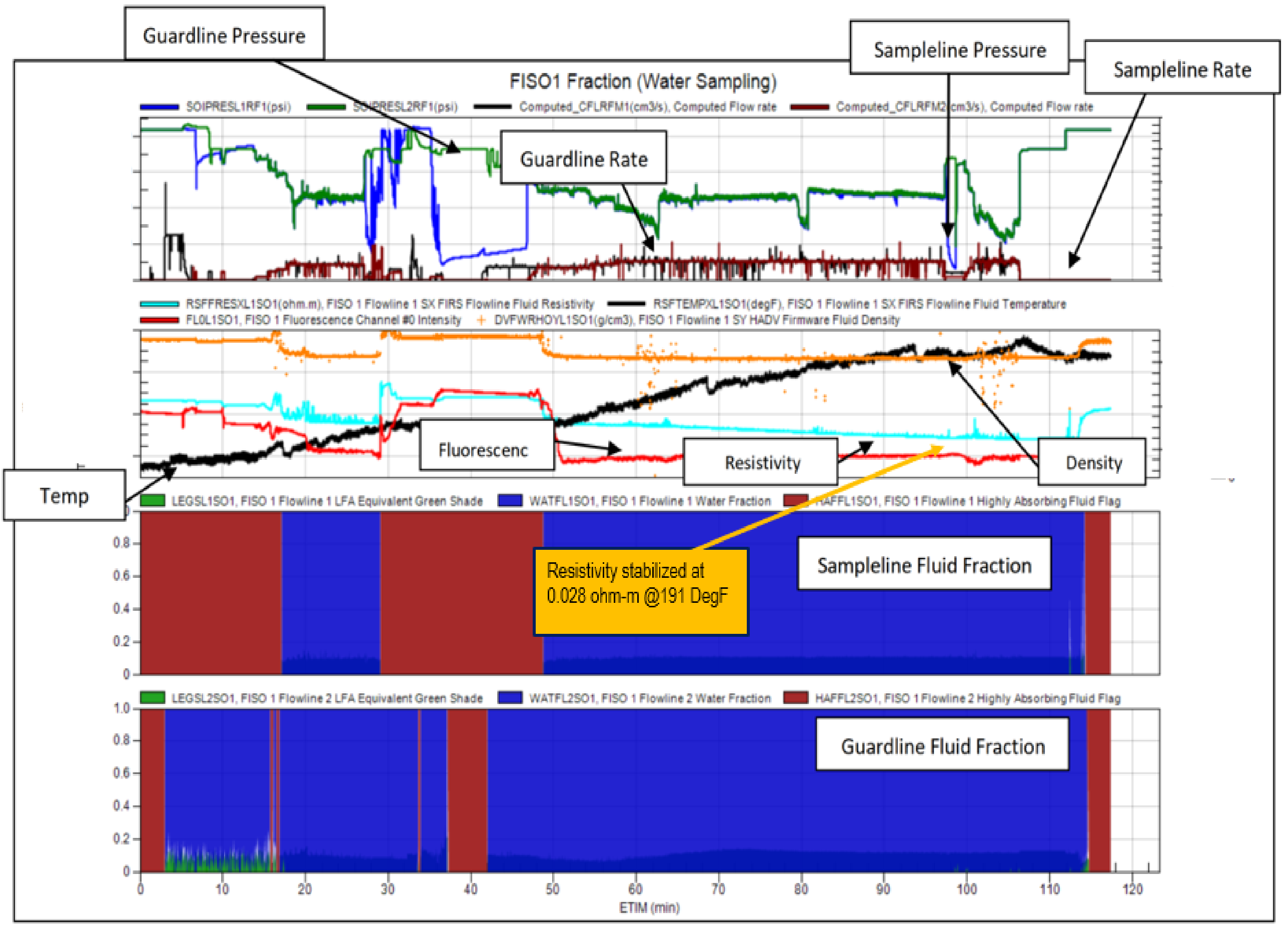


Figure 2 Saturation Profiling Downhole correction after accurate salinity input from bottom Zone A



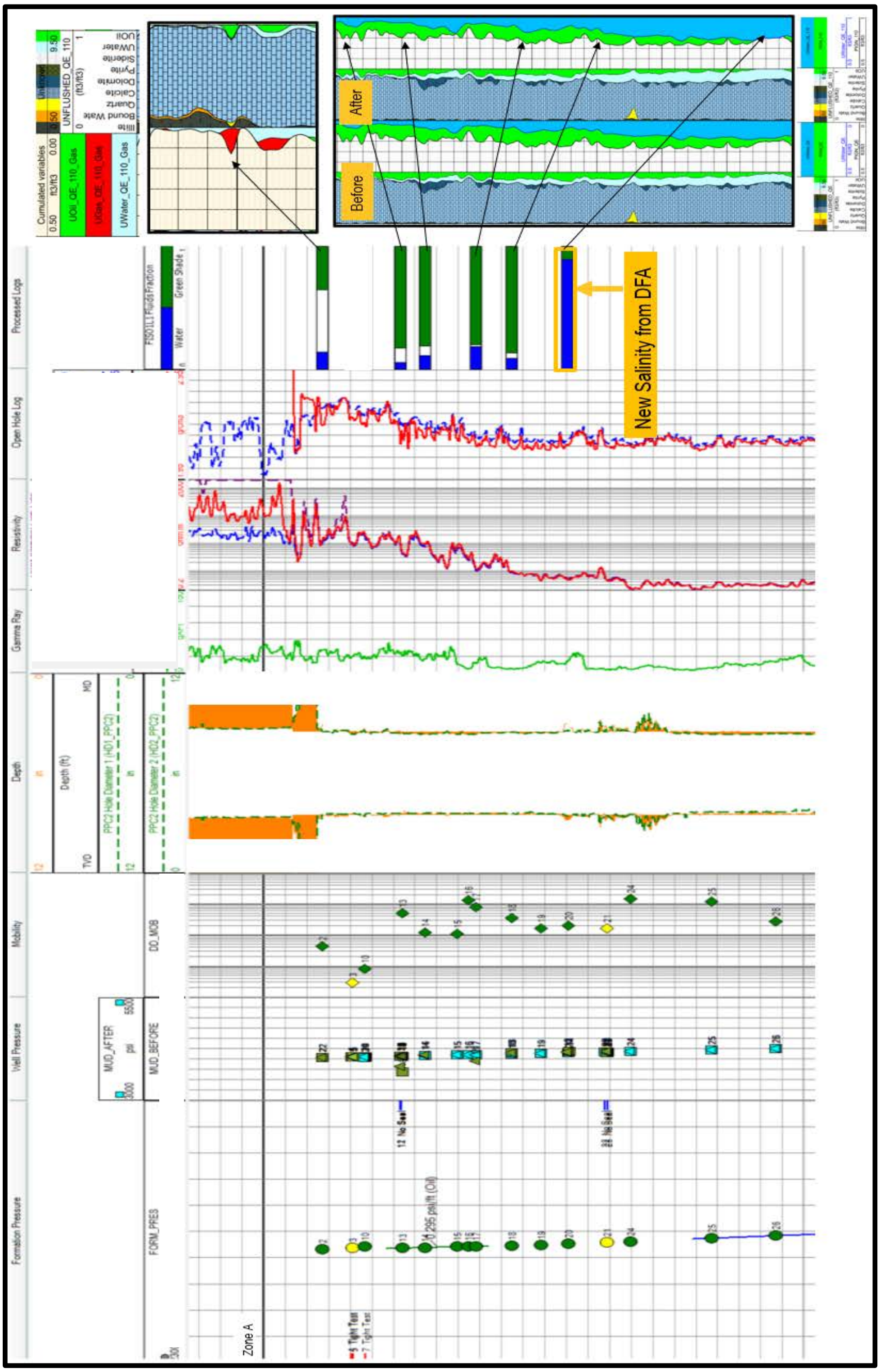


Figure 4 Integration of Open Hole logs with pressure & DFA after salinity correction

2. Reservoir Fluid Geodynamics using FHZ to assess connectivity

RFG workflows (Figure 5a) integrate comprehensive scientific foundation, Flory-Huggins-Zuo Equation of State (Figure 5b) with its reliance on the Yen-Mullins model of asphaltenes, fluid gradient, downhole fluid analysis (DFA), open hole logs and reference reservoir case studies that have enabled a systematic classification of RFG processes.

RFG is fundamentally a thermodynamic approach. DFA-measured asphaltene gradients and GOR gradients are generally not homogeneous and are treated within a thermodynamics framework to determine the extent of fluid equilibration. Asphaltene gradients can be measured with high accuracy and are critically important for RFG evaluation. Asphaltene gradients exhibit enormous and systematic variations associated with the light oil, black oil, and heavy oil models. All these gradients are treated by the FHZ EOS with its reliance on the Yen Mullins model.

The FHZ EOS for asphaltene gradients as well incorporates the sizes of asphaltene nanostructures to predict asphaltene gradients. The larger the particle, the bigger the gravitational gradient.

The RFG cases have shown that the presence of equilibrated asphaltenes throughout a reservoir indicates vertical/lateral connectivity on a production time frame (Figure 5c). For asphaltene equilibration to take place, there must be substantial fluid flow in the reservoir, unlike pressure equilibration, which requires relatively less mass flow.

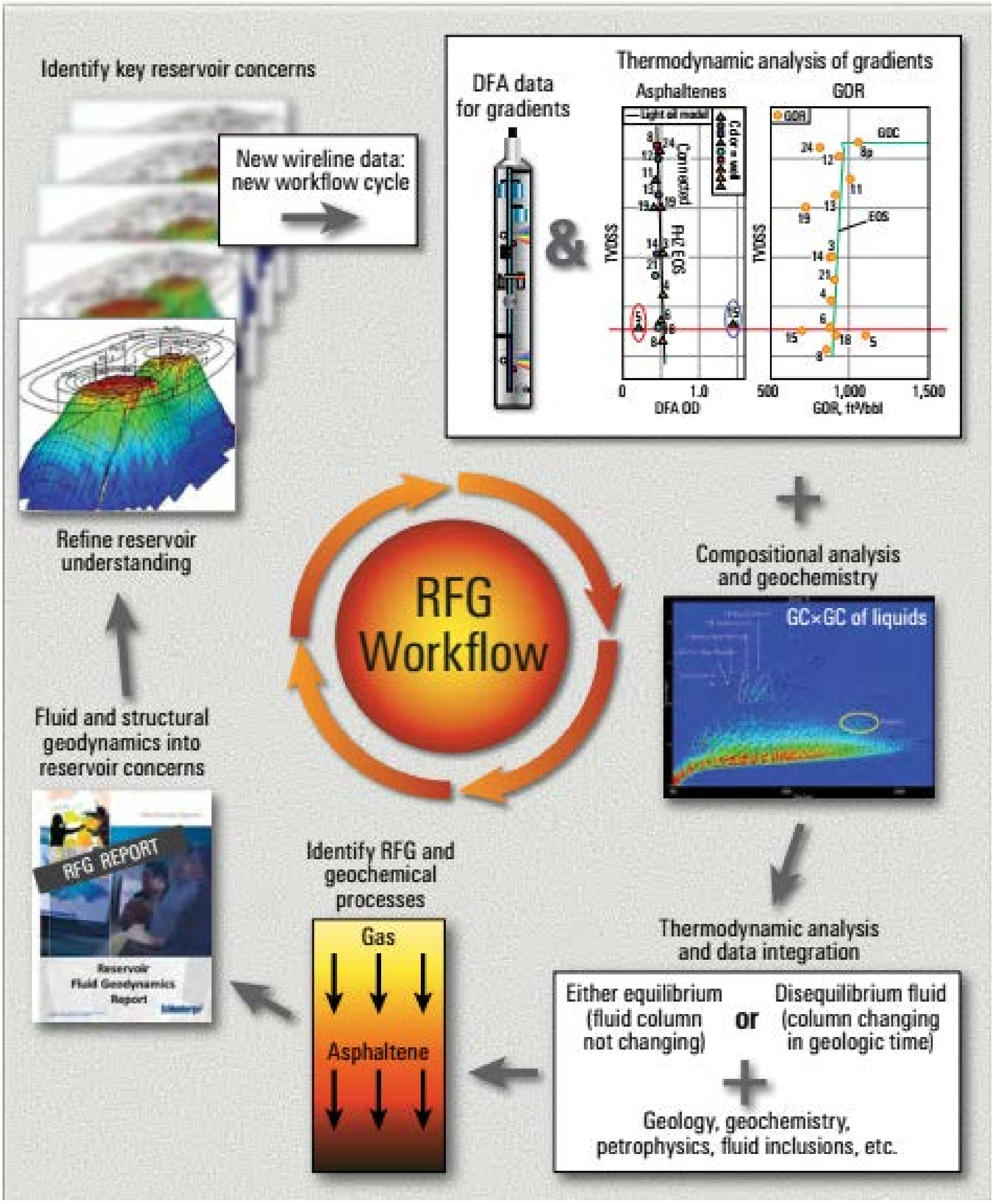
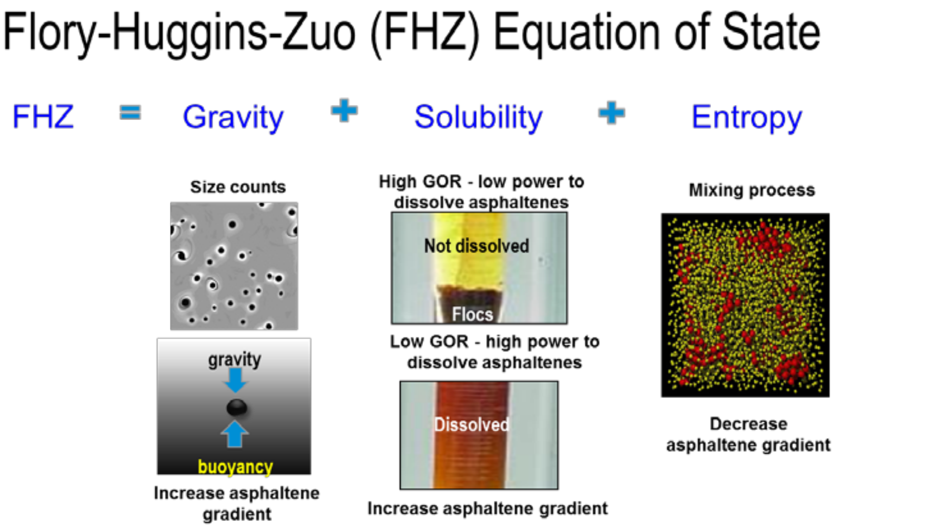


Figure 5a: RFG Workflow



$$\frac{OD(h_2)}{OD(h_1)}=\frac{\varphi_a\,(h_2)}{\varphi_a\,(h_1)}=exp\left\{\frac{v_a g(\rho-\rho_a)(h_2-h_1)}{R\,T}+\frac{v_a}{R\,T}\left[(\delta_a-\delta)^2_{h_1}-(\delta_a-\delta)^2_{h_2}\right]+\left[\left(\frac{v_a}{v}\right)_{h_2}-\left(\frac{v_a}{v}\right)_{h_1}\right]\right\}$$

Figure 5b: Flory-Huggins-Zuo Equation of state representation

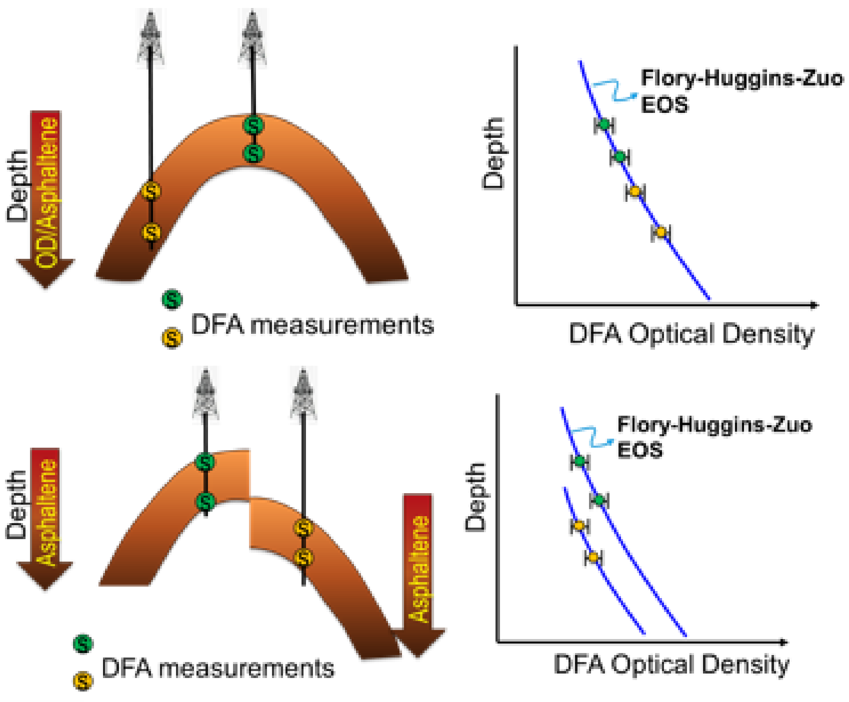


Figure 5c: RFG cartoons showing connected and disconnected reservoirs

The Wireline Formation Testers provide multiple applications to assess fluid characteristics and rock properties. These applications include Downhole Fluid Analysis & Vertical Interference Testing (VIT) which are integrated together along with open hole data to provide an accurate assessment of vertical connectivity & hydrocarbon / water types. However, such applications may not always be accurate in connectivity assessment depending on multiple environmental factors such as formation permeability, type of Hydrocarbon. For instance, pressure measurements may not always be conclusive due the effect of supercharging in tight formation, micro leaking due to poor mud cake (Figure 6: pressure masked by the undesired communication with the wellbore caused by leaky mudcake), low pressure pulse due to high permeability (Figure 7: The high horizontal permeability compensates the fluid faster than vertical fluid compensation causing no signal / signal below detectable level).
Also, relying on GOR, compositions alone in Down hole fluid analysis may not be conclusive due to the inaccuracy of the measurement at low GOR oil, OBMf contamination, presence of high-water fractions in the system (reduces accuracy of spectroscopic measurement) & sometimes causes emulsion. Density & viscosity resonating sensors may as well get affected by wettability & mud solids sometimes which affect the resonation frequency. Hence, impact on the accuracy of the measurements
Therefore, the new approach was designed to assess connectivity in such uncertain environment. This includes the use of Optical density Asphaltene gradient from the optical spectrometric measurement through Flory Huggins-Zuo (FHZ) equation of state (EOS) for asphaltene distributions. This as well can be extended to a Reservoir Fluid Geodynamics study when incorporating the field data & can be used to predict flow assurance area as well.
The approach consists of gathering multiple optical density measurements of hydrocarbon oil across the zone on assessment, having one measurement per depth. Each measurement is determined using a spectrometer that uses light in the visible and near infrared range to characterize the fluid flowing through the flowline to provide Optical Density values (Figure8). The optical density values are linear to the Asphaltene contents of the Hydrocarbon which can be used to assess connectivity of zones & fluid typing if it follows an asphaltene gradient (FHZ). This mostly happens due to the presence of equilibrated asphaltene throughout the reservoir.
The measurement interval selection is based on the best representative quality data, without any environmental effects (no high-water fractions , no solids). Its then undergoes the decontamination algorithm prior fitting in the FHZ plot.

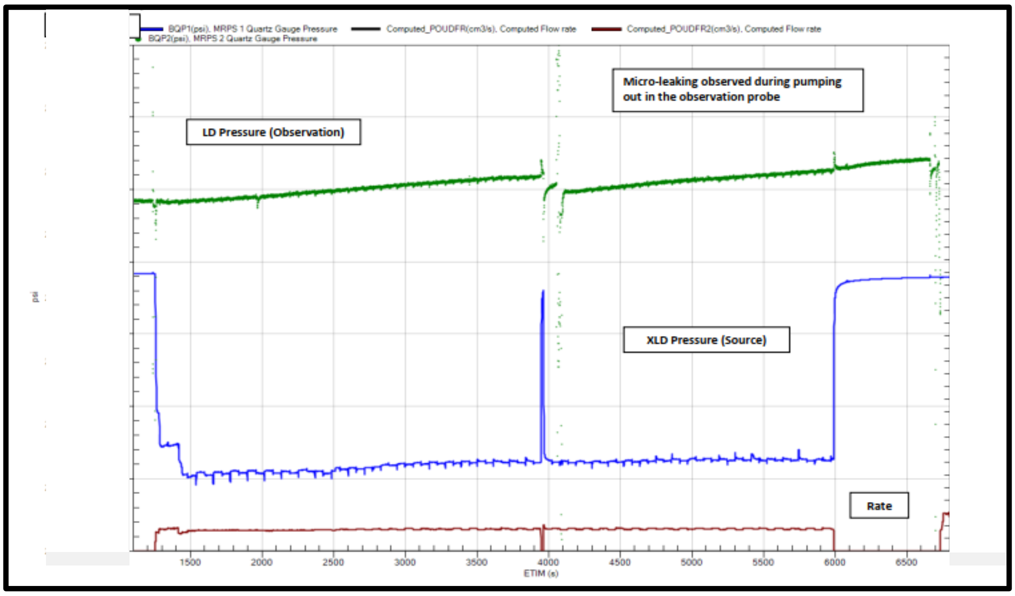


Figure 6 The Figure shows the response of a pressure observer probe over the multi signal generated by the drawdowns in the Source probe under micro leaking conditions. The pressure is masked by the undesired communication with the wellbore caused by leaky mudcake.

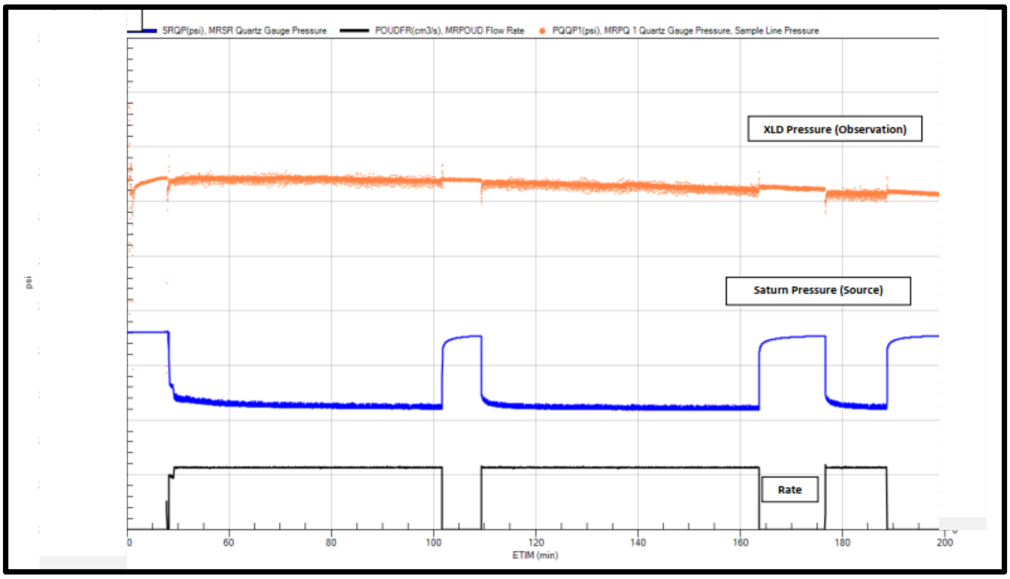


Figure 7 The Figure shows the response of a pressure observer probe over the multi signal generated by the drawdowns in the Source probe in a high permeability zone. The high horizontal permeability compensates the fluid faster than vertical fluid compensation causing no signal / signal below detectable level.

Connectivity Assessment and Fluid typing using FHZ-RFG

This new approach shows that by using FHZ asphaltene gradient from acquired optical density spectroscopy data, zonal connectivity & fluid typing can be determined. The FHZ asphaltene gradient shows that the data acquired ~103 ft interval from the 4 Hydrocarbon points fits into an asphaltene gradient of 5nm of asphaltene molecule size (Figure 8). Conducting a Vertical Interference Test with such high spacing length between the active probe and the observer probe may be inconclusive due to the pressure pulse signal from the active probe will decay before reaching the pressure observer probe as the horizontal fluid compensation movement will be faster than the vertical fluid compensation movement resulting in an inconclusive test.
The FHZ asphaltene gradient also shows that with the increase of depth prior reaching close to OWC zone (~150 ft) more tendency to have asphaltene percentages (more asphaltene particles settling down – brown track) which may lead to flow assurance concerns during production phase. This can be also tested by conducting downhole CCE Test (Constant Compositional Expansion) to determine the AOP (Asphaltene Onset Pressure) using the Wireline formation Tester by trapping the fluid in the tool flowline & slowly decompressing it by using very slow rate pumps while monitoring the optical spectrum color, fluorescence details changes. The high asphaltene content and viscosity indicates the possibility of occurrence of heavy oil or tar (mat or patches), which will impede both injectivity and productivity.

This approach can be widely used in other exploration & development fields where fluids compositional analysis, GOR, density & viscosity are very close, or where there are measurement uncertainties. Sometimes, the pressure measurements also can be inconclusive due to reservoir dynamics taking place, supercharging effects, different pressure gauge offset between multiple wells & different tools.
In our case, only 3 points were possible to construct an oil gradient of 0.29 psi/ft (figure 9). Adding more points were affecting the gradient & causing it to be a bit higher. With the lack of knowledge on the reservoir pressure dynamics taking place (depletion pr injection), it will be tough to get reliable gradients and its extent, and the confidence will be a bit low. This indicates the strength of the FHZ asphaltene gradient methodology in such environments regardless of the reservoir dynamics taking place.

The validation of FHZ asphaltene gradient results with the laboratory results provided from previous cases (IPTC-23035) can lead to optimization of the number of sampling & down-hole fluid analysis (DFA) stations. The confidence provided in the methodology would prevent acquiring more samples for analysis from different parts of the fields if few acquired stations follow the same FHZ asphaltene gradient, as it will confirm field connectivity & fluid typing. Hence saving cost, time & CO_2 emissions associated with the rig & laboratory analysis.

The asphaltene gradient established per zone can as well give a quality control point of the expected predicted optical density values which can be later used to assess the contamination levels & prevent extended station pumping, saving more rig time, cost & CO_2 emissions during real-time.

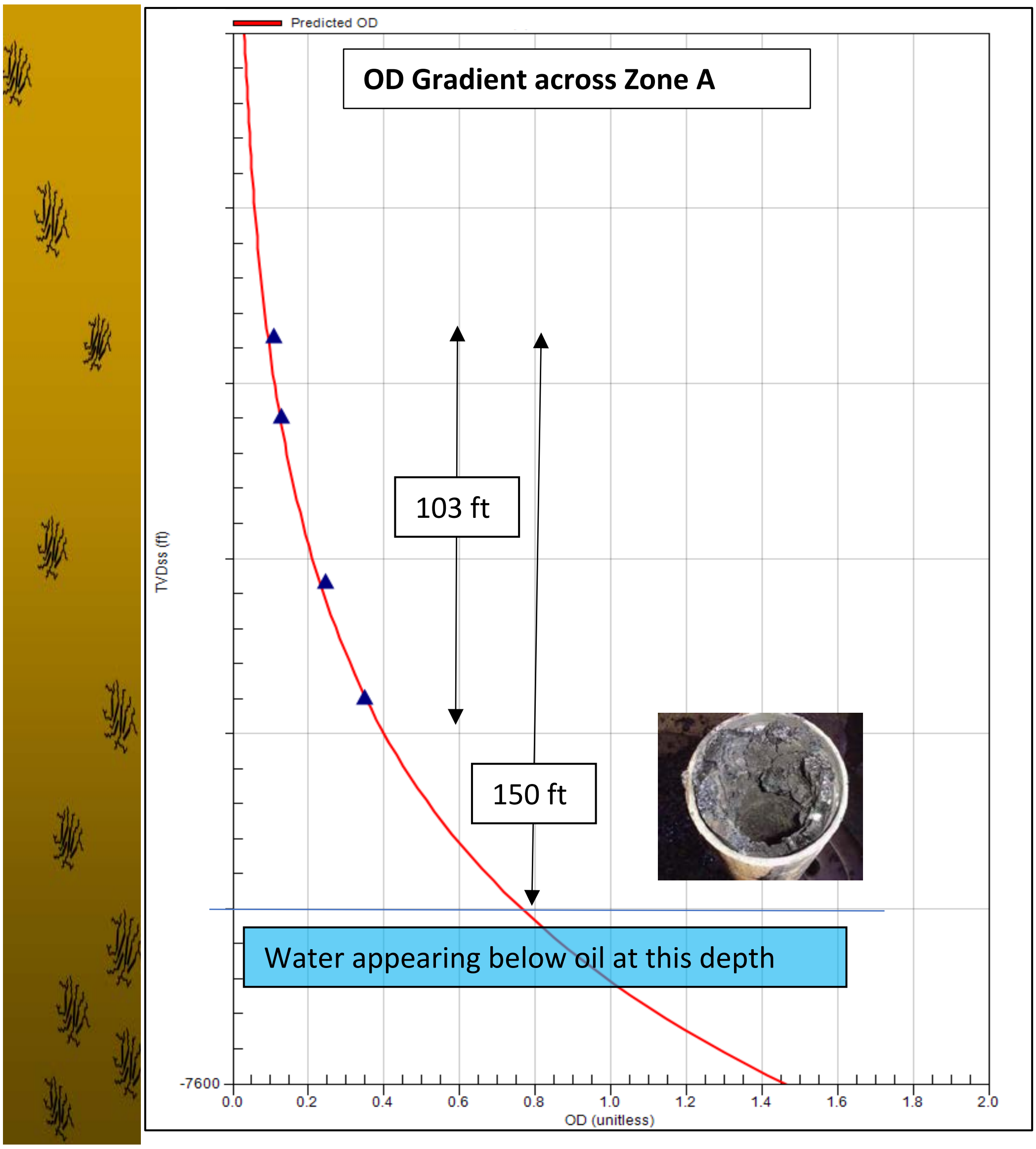


Figure 8: RFG OD gradient along Zone A showing an increase with asphaltene percentage with depth. The right image shows the increase of asphaltene percentages towards the bottom section

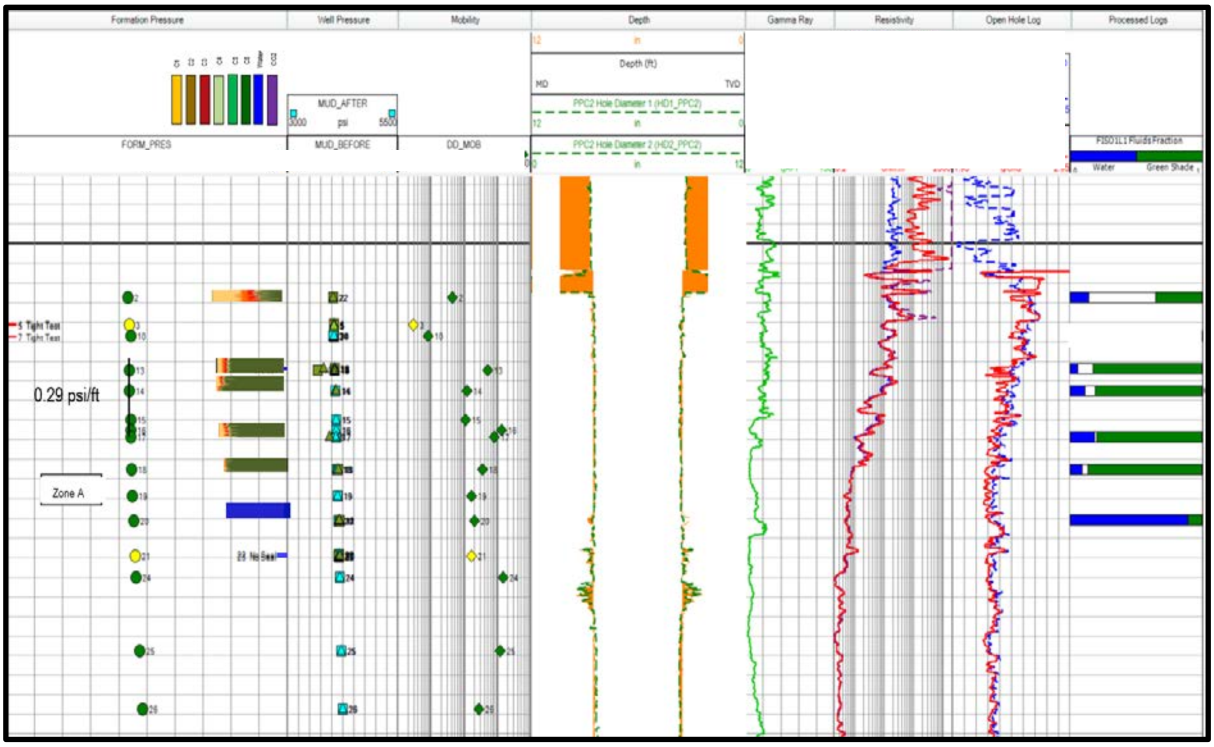


Figure 9:The Figure shows that pressure gradient may not always be conclusive & cannot alone determine the vertical extent of the reservoir. The yellow area represents only 3 points where a good quality gradient was constructed.

Results and Conclusions

- Saturation profiling and reservoir connectivity assessment is crucial for the understanding of the reservoir extent & reserves estimations
- Conventional methods of using salinity from nearby fields is inaccurate and time consuming as it depends on the initial water sampling quality & the time it takes to get analyzed in the lab. This in accuracy will affect the hydrocarbon vertical extent & reserves. Also, will results in sampling / DFA unnecessary stations
- Acquiring InSitu salinity measurement in real-time to reconstruct the petrophysical model saturation profiling resulted in accurate hydrocarbon extent identification & reserves estimation. This also saved unnecessary sampling / DFA stations to confirm hydrocarbon – water fractions. Hence saving time cost & CO2 emissions.

- Reservoir connectivity assessment requires certain criteria to get reliable results as it is sometimes inconclusive due to formation tightness, leaky mud cake, high permeability & length of the tested interval.
- The FHZ asphaltene gradient (RFG application) is a new approach to assess connectivity under any conditions and is not affected by reservoir dynamics (depletion or injection) nor wellbore & formation effects like pressure Vertical Interference Testing.
- The FHZ asphaltene gradient can be extended to assist in the prediction of flow assurance production challenges when integrated with other open hole data & measurements.

Acknowledgement

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