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Multifaceted application of Cased Hole Formation Resistivity tool- A study from brown field

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Abstract

Periodic reservoir surveillance in terms of saturation monitoring and movement of fluid contacts owing to prolonged production is of paramount importance for keeping alive any mature field. Apart from drilling new wells, another way out to maintain sustained production may be optimizing the production from old wells. Tapping the bypassed oil and monitoring the movement of OWC in time lapse are required to get sustained oil production from old wells. One of the available methods to estimate the present day oil saturation behind casing is Cased hole formation resistivity measurement. The introduction of cased hole formation resistivity (CHFR) measurement makes it possible to record deep measurements of the prevailing formation resistivity behind casing with precision and thereby comparing the open hole formation resistivity with the CHFR measurement depletion since inception can be measured. The completion interval can be selectively chosen based on the CHFR result. The area of present study comprises non-Archie sandstone reservoir. The fields discussed here are at mature stage and production is constantly declining. This paper will describe how the CHFR measurement made it possible to identify the undrained zones in some old wells. It will also describe how CHFR brings success to the well where open hole could not be recorded in the final section due to borehole complexities & repeated held ups and pay sands were identified solely on the basis of CHFR log and cased hole neutron (CNL) measurement. The theme of the paper is judicious application of state of art technology for brown field production enhancement.

Introduction

Most of the major producing oil fields in India were discovered in 1960’s and 1970’s and after sustained production for more than 4 decades they have been classified as brown fields. In order to improve the productivity from a field it is very essential to maintain the health of the reservoir by tracking any changes in the Resistivity and thereby knowing the present day saturations, and also monitoring the movement of fluid contact. Movement of fluid contacts and cased hole hydrocarbon saturation monitoring was carried out in earlier days by Nuclear tool which is still being used, however, these tools have very low depth of investigation and also have its own limitations in areas of low porosity (<15%) and salinity. However, with the advent of CHFR, the measurement of Resistivity behind casing has become a reality in terms of significantly deep measurements with respect to open hole resistivity measurements.

For sustained production and productivity of any brown field it is imperative that we look for bypassed and undrained hydrocarbons due to non-uniform drainage as inhomogeneity and complex mineralogy also add to complexities within the reservoir. The very concept of CHFR came in ‘30s. It is due to improved measurement hardware, we are now able to measure very small order of Resistivities and currents which were unthinkable at one point of time. CHFR measurement coupled with porosity measurement can provide correct picture of the reservoir even in cased hole situations. These measurement when is compared with open hole saturation measurement gives the estimation of the depletion and remaining zones of the bypassed oil. The study area is a brown field in the North-Eastern India discovered in 60’s. The reservoirs are mainly clastic and have active bottom water drive mechanism. From the field perspective, they are facing significant production decline over recent years due to severe problems in high water cut, water coning, saturation depletion owing to prolonged production and liquid lifting problem due to pressure drop. More over water shut off operations are only sustainable upto 6-7 months due to rapid rise of fluid contacts. The fields in the current discussion have very high well density almost in all blocks of the fields. Though the fields are situated at different structures but the production profile of the wells of different fields suffers from same problem. In these circumstances it is very much essential to assess the production sustainability of fields from different view point. Due to spatial heterogeneity of reservoir rocks with in the block itself, it is very much difficult to correlate old wells' saturation by comparing the open hole logs of newly drilled vicinity wells. In many occasions of work over operation for zone transfer this exercise comes out to be futile. Considering the complicacies in correctly estimating the bypassed oil and saturation depletion, cased hole formation resistivity measurement has been introduced and from the outcome it really opened up a new window of production optimization from the old wells. A number of wells are being logged using CHFR in the present area in context. Each of the discussed wells was logged with different themes. The logs depicted the depletion as wells as undrained portions of the reservoir. This paper contain some case histories and success stories of tapping the undrained portion of the reservoir from different fields of the study area and incremental oil gain by judiciously selecting the perforation interval on the basis of CHFR.

Tool Principle

The CHFR is essentially a laterolog where we determine the formation Resistivity (R_t) by measurement of V_o and ΔI (Fig-1), however the measurement in CHFR becomes more difficult because of the presence of huge conductor casing. The CHFR tool (Fig-2) consists of a current injection electrode at the top with 4 sets of measuring voltage electrodes spaced 2 ft. apart and each set of electrode consisting of 3 pads connected in parallel spaced 120° apart thereby providing improved contact with the casing followed by a current return electrode which also acts a centralizer.

The measurement in CHFR is made in 2 steps. In the first step a low frequency alternating current is injected into the casing and the tool measures the difference in current going down by measuring the potential difference between any 3rd of the 4th voltage electrodes. In the second step which is the calibration step a current is again injected from the top injection electrode to the bottom electrode thus giving R_C; the casing resistance. Because the formation currents are measured through a drop in the casing resistance the actual measurement is made in the nanoVolt range. AC current is sent through casing to avoid the polarization and drift. Readings are taken in stationary condition to avoid random noise. The precision of the measurement is limited to the formation resistivity range 1-100 ohm-m. The cement thickness, cement bond and cement resistivity are the parameters which affect the CHFR measurement. Proper cement correction and tool calibration with open hole log, in shale or some unexploited zones, is applied for getting correct picture of the present reservoir condition. The quantity "Depletion Index" defines how much hydrocarbon has been produced from the reservoir from its initial condition. It is basically the square root of the ratio of cased hole resistivity to open hole resistivity.

Depletion Index (DI) = $\sqrt{(\mathbf{R_{CHFR}/R_{OH}})}$

Study area

The area of present study is a brown field situate in the North-East India. From depositional point of view the area is a shelf regime and whole pile of sediments rests over weathered metamorphic basement of Precambrian age. The sediments are of fluvial to marginal marine environment deposits. Total 14 pays are developed in the field of age Middle Eocene to Pliocene. Pays at the stratigraphically top position are of Miocene to Pliocene age and are of Fluvial origin comprising dominantly sandstone with clays with in it. These pays are followed by pays of late Eocene to Oligocene age and are Deltaic deposit comprising coal shale and Sand sequences. The bottom most pays are of Middle Eocene to Lower Eocene age and environment of deposition varies from open marine-platformal to distal alluvial fan and braided river.

All the fields described in this paper have heterogeneous and complex lithological features. Structural evolution of the area is also complex and the area is affected by many fault networks. Structural correlation and lithological evaluation in this part becomes very difficult. Apart from discussed examples in this paper many more notable and interesting examples are available in this area where application CHFR was successful.

Case studies

Well X-404:

The well X-404 was drilled as a development in Apr-1991 in field X with the objective of exploiting S-2 pay of Miocene age. The field X is producing since 1963 from multiple pay sands. The S-2 reservoir is the prolific producer in this field and most of the wells are completed in this sand. The reservoir has strong aquifer support and due to prolonged production significant rise in oil water contact has been taken place. Most of the wells completed in this sand are currently producing with more than 90% water cut. The well X-404 was completed in this sand & production started in July-1991 from S-2 @ Q_o=14m^3/d with WC=14% on self. Six work overs have already been carried out upto 2008 for installation of artificial lifts and water shutoff followed by selective perforations. The well was ceased to flow since Sep-2011 with last rate Q_L=2 m^3/d, WC=95%, Q_o=0.1 m^3/d after producing N_p=54000t of oil from **S-2** sand. Well was taken for workover in 2013 for depletion monitoring in S-2 and find out left out oil in S-2 sand. With this very objective CHFR logging was carried out in and it was found that the top of the S-2 reservoir is still undrained. After squeezing cement in the open interval X472- X479m the top of the sand in the interval X477.5-X480m where CHFR showed (Fig-4) no depletion, was perforated and on activation it produced oil. The well is still producing @ 48m^3/d with 80% WC. Nearby wells X-399, X-248, X-417 are completed in same sand unit but producing with high water cut. The deployment of CHFR results 9.6 m^3/d oil gain from this well.

Well Y-156

The well Y-156 was drilled in Y field in 1988 as a Water Injector in S-5A sand of Miocene age. The field was discovered in 1968 and has areal extent of ~25 km^2. Commercial oil production is established in prospects of Miocene, Oligocene and Eocene age. The field has highly faulted multilayered heterogeneous reservoir. Miocene reservoirs hold the largest amount oil in place in this field. In the present well S-3, S-4, S-5A, S-5B pays were encountered and all are interpreted as hydrocarbon bearing. The well has been tested in S-5B, S-5A, & S-4 sands and until 2013 it was on comingled production from S-4B +S-5A pays. The well ceased to flow in Sep-2013. Zone transfer to upper prospect was decided to resume the production based on the production profile of nearby wells. Prior to that CHFR log (Fig-3) was carried out covering S-3 sand to see the depletion in S-3 as some of the nearby wells were already producing from S-3. It was found that the S-3 sand encountered in this wells is not affected by the production of the nearby wells from S-3 sand. Based on the CHFR result zone transfer to S-3 sand was carried out in the intervals X487 – X493 m, X498 – X501 m. The well is currently producing at a rate Q_L=12 m^3/d, WC=1%, Q_o=11.9m^3/d.

Well Y-129A

The well Y-129A was drilled as a development well in 2013 for S-3 and S-5A sands of Miocene prospect. While recording open hole logs in final section tool got held up twice & log could not be recorded upto TD. In view of severe drilling complications at the final section, the hole was cased and CHFR, cased hole neutron (CNL) (Fig-5) and CBL-VDL logs were recorded covering S-5A sand. Based on the CHFR-CNL log and structural correlation with nearby producing wells two intervals in S-5A were perforated and the well flowed @Qo=40m^3/d with 5.2% WC in initial production testing. The well is currently producing @ Q_L=40m^3/d with 5.3% WC from the same reservoir.

Well Z-12

The well Z-12 was drilled as a development in 1990 in field Z with the objective of exploiting S-MS pay of Late Eocene prospect. The field was discovered in 1976 with first oil stuck in Late-Eocene reservoir. The well Z-12 has penetrated 12 pays comprising Oligocene to Pliocene above the objective sands. All the sands encountered in Oligocene- Pliocene prospect in this well are found to be bearing from log interpretation. The well was completed in S-MS sand and on initial production testing it produced @ 128 m^3/d oil. Since Inception to 2009 the well has undergone six numbers of workover operations for reperforation and water shutoff in the same sand. Until 7th workover the well was completed in the interval X815- X823 m in S-MS sand. In Jan- 2014 7th workover operation was taken up for water shut off and identifying the zones of left out oil. With this objective CHFR logging ((Fig-6) was carried out and based on the result, open interval was squeezed and two intervals X812- X817m & X832- X834m was opened and well produced oil on self after activation. The well is still producing from the S-MS sand.

Conclusion

In a depleted oil reservoir where there is common problem of high water cut owing to shift in OWC with time due to prolonged production CHFR measurement can be one of the best methods for identifying the bypassed oil for maintaining the production. As the CHFR measurement is highly affected by the cement condition behind casing, it is always recommended to run cement bong log before acquiring CHFR data. The calibration point i.e. shale or undisturbed zone should be chosen with proper care as all the result of the CHFR measurement depends how the calibration points are taken. CHFR measurement is 10 times deeper than the cased hole nuclear measurements and thus the log is hardly affected by the rugosity and bad bore hole conditions like washout, caving etc. It also gives good results in low porosity reservoirs. In the present area of study the CHFR measurement has got huge success in different aspect in terms of incremental oil gain.

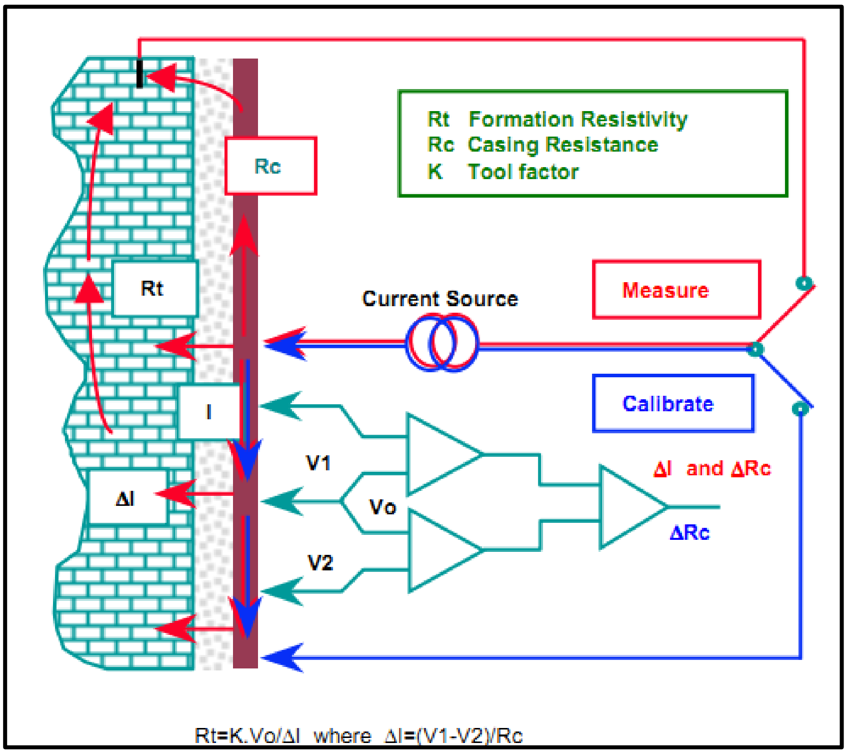

Fig-1: CHFR measurement principle (Schematic)

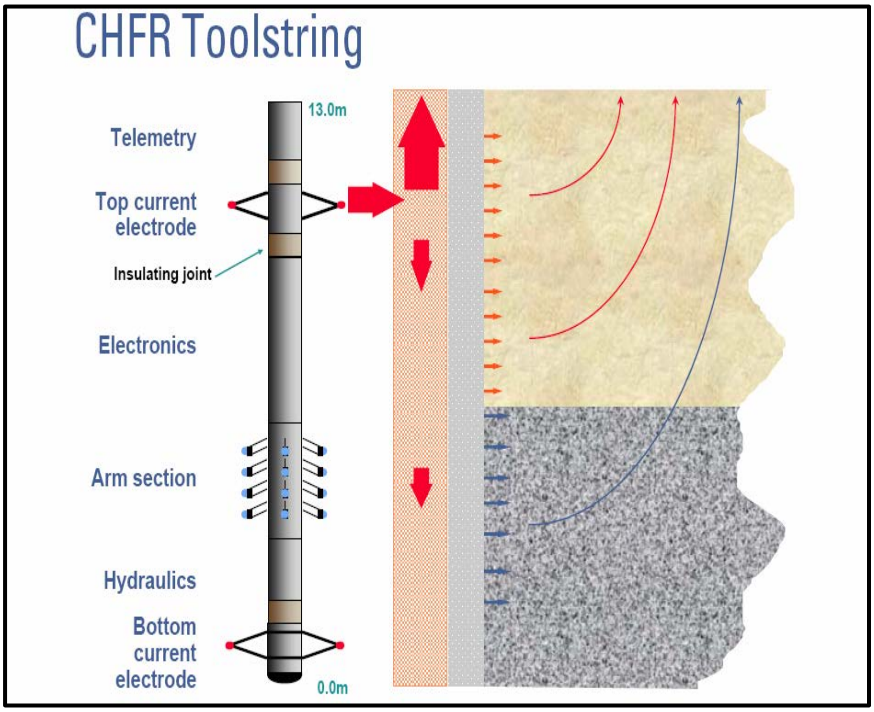

Fig-2: CHFR Tool String

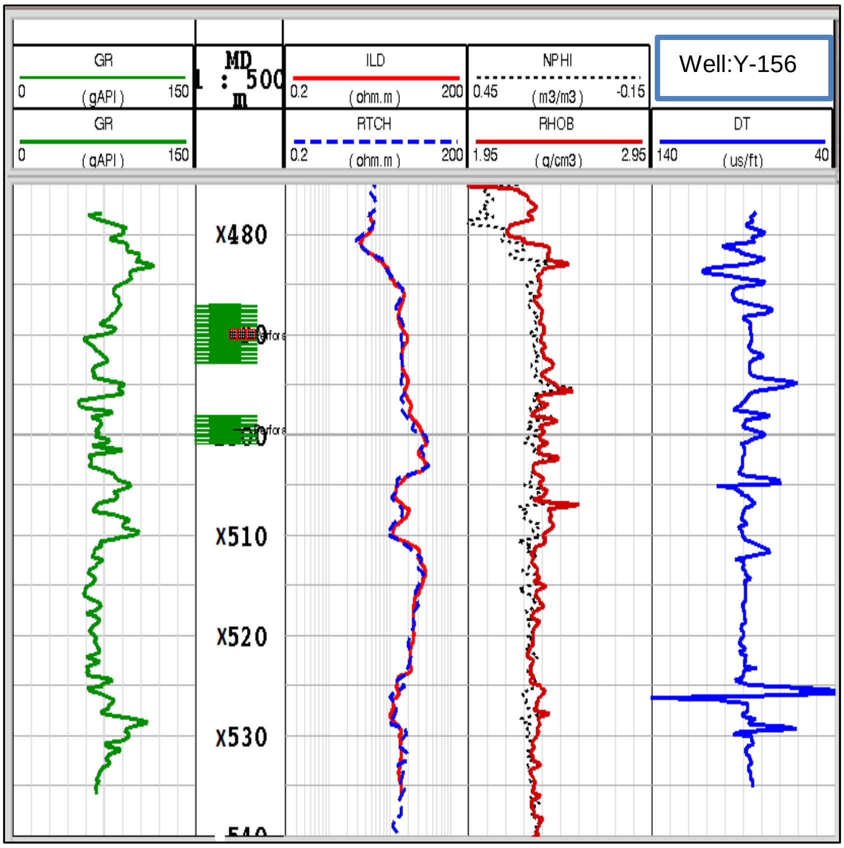

Fig-3: Z/T to S-3 sand from S-4B +S-5A1 sand in well **Y-156** (Green marking shows the present perforated zones)

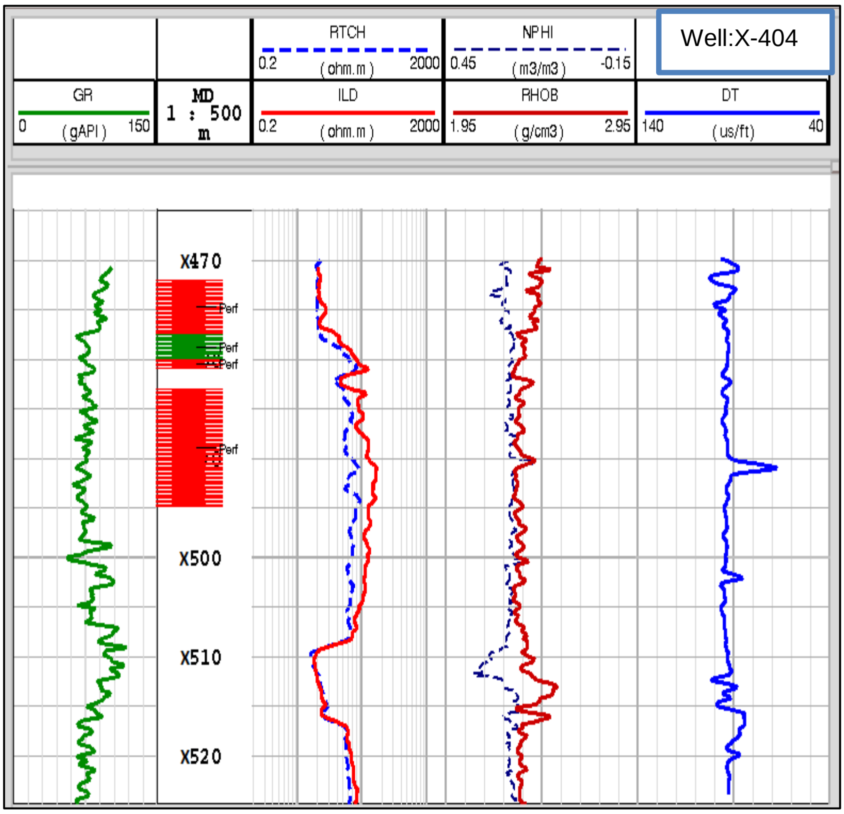

Fig-4: Selective perforation in S-2 sand in well **X-404** based on CHFR result (Green marking shows current completion, while reds are previously perforated zones)

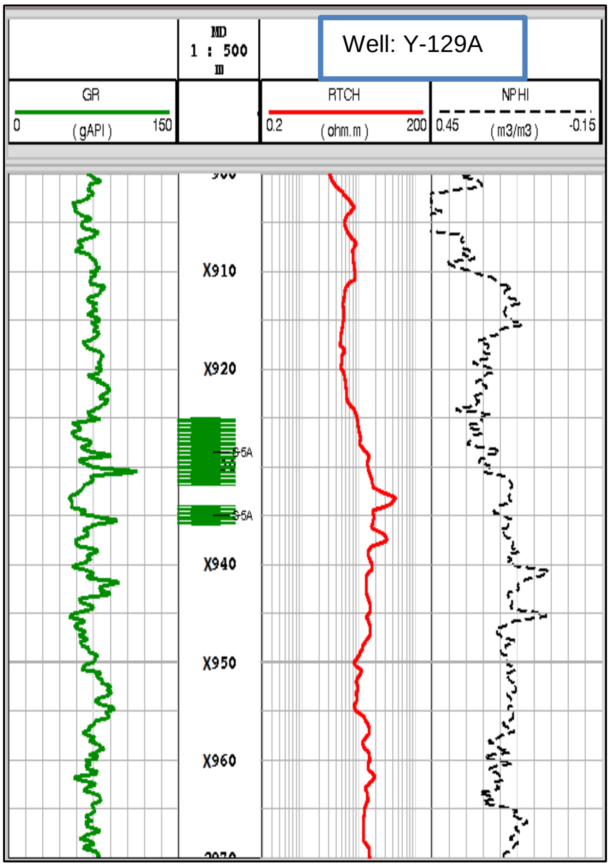

Fig-5: Well **Y-129A**. Open hole logs could not be recorded due to severe drilling complication and repeated held ups. Perforation was carried out based on CHFR and CNL log.

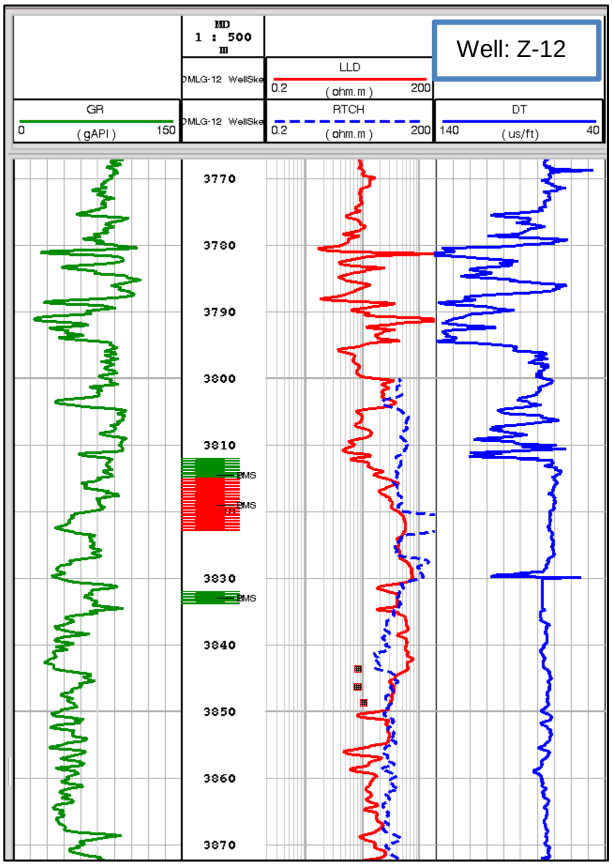

Fig-6: Selective perforation in well **Z-12** based on CHFR result (Reds are previous perforation while greens are current perforation intervals.

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