Application of Cased Hole Formation Resistivity tool- Brown field revival and contingency perspective

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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 of highly shaly, silty reservoirs bearing moderate porosity and moderate to very low permeability. 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.

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. Though the concept of CHFR came in 1930s, 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 environments. These measurements 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 Western India discovered in 60's. The reservoirs are mainly clastic. 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. 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 contains 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 and using CHFR as contingency logging is problematic wells and subsequent completion of the wells hydrocarbon producers.

Tool Principle

The CHFR is essentially a laterolog where we determine the formation Resistivity (Rt) by measurement of Vo 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 RC; 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) = √(RCHFR/ROH)

Study area

The area of present study is a brown field situate in the Western India. The sediment filling of the basin can be attributed to N-NE to S-SW flowing river system along the basin and depositing the sediments eroded from Aravalli-Delhi Highlands. There is a regular gradation of sediments deposition along the basin from a sand-shale-coal sequence in the north to siltstone-shale sequence in the southern part to the shale facies and finally carbonates in the Mumbai-Offshore Basin. The lower Eocene Cambay shale Formation is the main source rock in the basin while the fluvial-deltaic Kalol and Kadi formations of Eocene age are the main reservoir rocks. Tarapur shale is the regional or local cap rock of the basin.

All the fields described in this paper have heterogeneous and complex lithological features. The major challenges faced in such reservoirs is re-assessment of the producing reservoirs due to changing reservoir dynamics after production for decades in terms of uncertainty in mapping of fluid margins, reservoir connectivity and unswept hydrocarbon etc. Additionally, the absence of full set of basic logs for formation evaluation makes the situation more challenging. The main challenge faced in fields of Ahmedabad is that the pay sands are highly silty in nature, bearing moderate porosity and moderate to very low permeable. Pay sands of the fields are developed just below / above the coal layers, and are carbonaceous in nature. The reservoir complexity makes its interpretation and hydrocarbon production difficult. As these sands are highly shaly and silty (fine grains) have limited porosity and few interconnected pores, HF is required to raise the production index of the reservoir. Without hydraulic fracturing, this sand would produce too little oil and/or gas and the cost to drill and complete the well would be could not be justified by this low rate of production. In many wells, re-HF is required for sustained production.

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-1

The well X-1 was drilled as an inclined 'L' profile development well up to the measured depth of 1661m against the set target depth of 1661m with the objective as Oil producer in A-1 pay sand. Open hole logs could not be recorded due to well complication. CHFR-GR and CHN-GR logs were recorded in the intervals 1400-1623m & 1300-1633m respectively. In A-1 pay, the interval 1566-1571m (Fig-3) was interpreted as hydrocarbon bearing and the same were perforated via TCP. 150 litres of oil was observed during testing. Well was concluded as Oil bearing in A-1 pay sand, completed with hydraulic packer.

Well Y-1

The well Y- 1 was drilled as an inclined 'L' profile development well up to the measured depth of 1958m with as Oil producer. Due to well complications, open hole logging couldn't be carried out in this well. It was decided to record the logs in cased hole. After casing and cementation, CBL-VDL-GR-CCL, CAST-GR-CCL, CHFR-GR and Cased Hole Neutron-GR logs were recorded in the intervals 1300-1897m, 1300-1907m, 1320-1883m and 1200-1912m respectively. In B-2 pay sand, the interval 1832-1837m (Fig-4) interpreted as hydrocarbon bearing based on CHFR log and the same was perforated conventionally @ 18 SPM. During initial testing, 5.4 m3 of oil and some gas was observed. Well was concluded as Oil bearing in B-2 pay sand.

Well Z-1

The well Z-1 was drilled as a development well in 1966 for C-1 horizon. On the basis of comprehensive log analysis, the interval 1559-1570m in C-1 pay sand was tested. The well flowed oil @ 135.4m3/day through 5mm bean on self. The zone contributed to a cumulative oil production of 372807 m3 and gas production of 51735613 m3, till March 2022, after which, the well was ceased due to 90% water cut. Hence, it was decided to record CHFR-GR log to find out the remaining oil saturation in C-1 pay sand. CHFR-GR log was recorded in the interval 1550-1580m and the results are shown in Fig- 5.

CHFR log indicates that the interval 1561.5-1572m has been depleted but there is some hydrocarbon still intact in the interval 1559-1561.5m. Thus, on the basis of CHFR results, selective perforation was carried out in the interval 1559-1562m in C-1 pay sand (Fig-5). Upon testing, the well flowed oil @ 4.15m3/day on SRP. Presently, the well is flowing oil @ 3.86m3/day and gas @ 834m3/day with W/C: 41% on SRP. The zone has contributed to a cumulative oil production of 1222 m3 and gas production of 205221 m3 on SRP till May, 2023.

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.

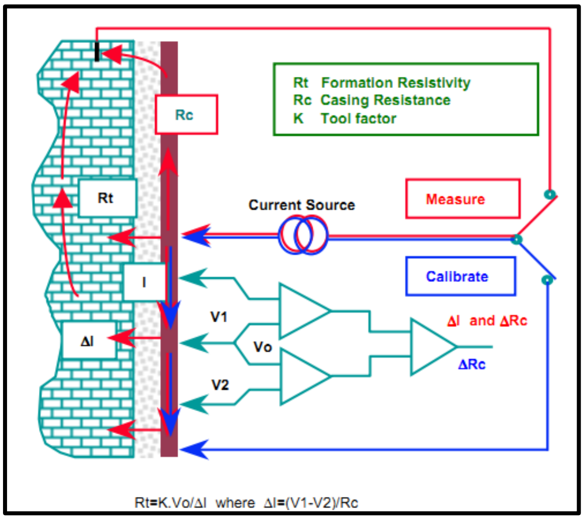

Fig-1: CHFR measurement principle (Schematic)

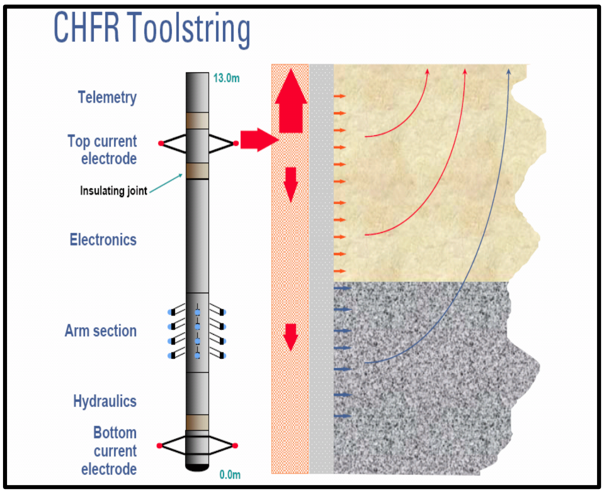

Fig-2: CHFR Tool String

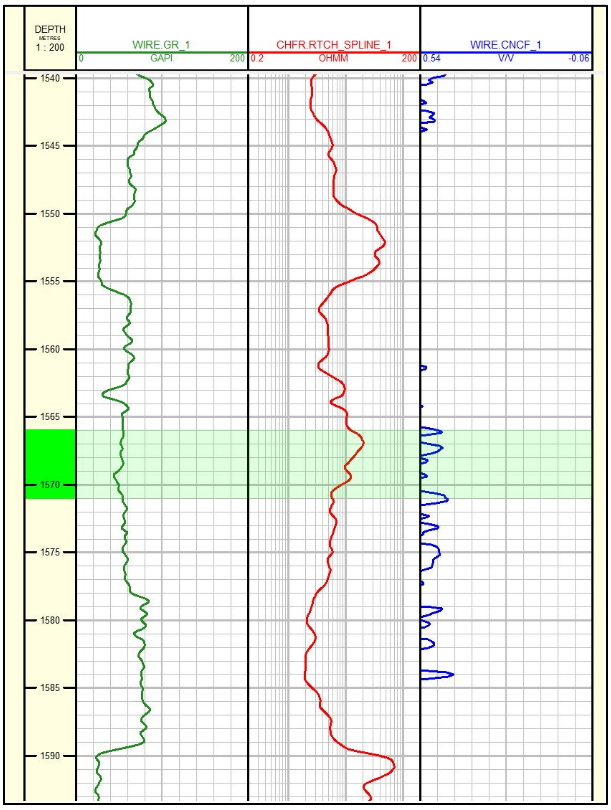

Fig-3: Log motif of Well-X-1.

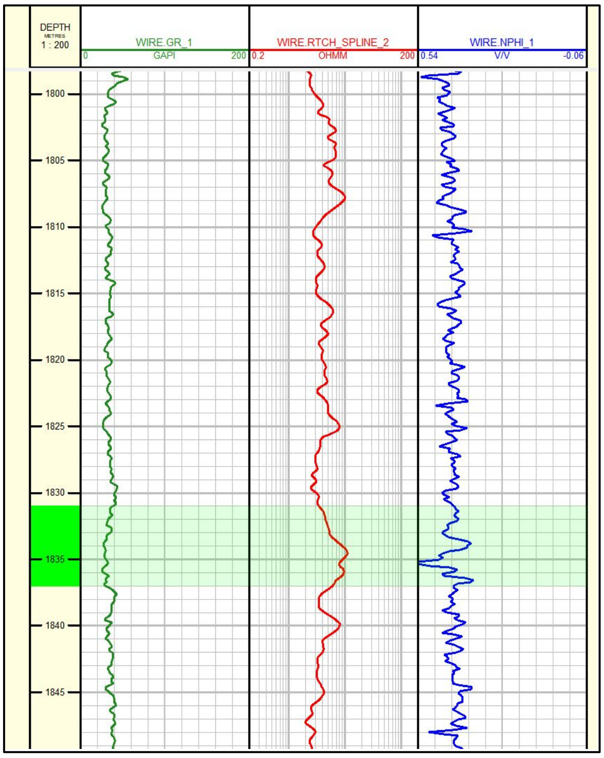

Fig-4: Log motif of Well-Y-1.

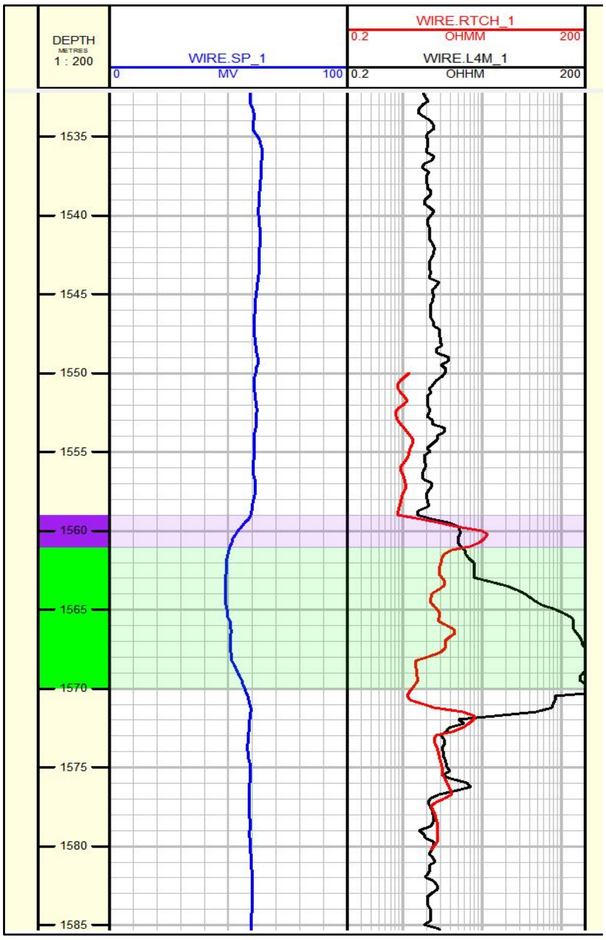

Fig-5: Log motif of Well-Z-1.

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