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# Well Logging a viable tool in exploration (A case study of well 2 of Koko field of Niger-Delta, Nigeria)

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**ABSTRACT**

Well-2 of Koko field was drilled as an exploratory well, and various analytical tests aimed at determining the petrochemical characteristics of the reservoir sand, was utilized in the evaluation of the hydrocarbon prospect of the area. The gamma ray log, resistivety/inductivity log, compensated neutron were used in getting the above information, through the identification of the various lithologic units present in the well. From the information got from the various logs, it can be inferred that the hydrocarbon prospect of the area is low at the present depth of investigation.



## Introduction

Oil and gas exploration started in Nigeria when from 1908 to 1914, the German Nigeria Bitumen Corporation and the British Colonia Company, drilled about 15 holes from dip from the heavy oil seeps which occur in the cretaceous Abeokuta formation, Okitipupa situated at approximately 60 miles east of Lagos. The venture was however, abandoned as a result of dry holes. The work was stalled because of world was 1. Interest in exploration died down in the 1920s and early 1930s, but from 1937 to 1940, interest was resurrected again when Shell D' Arcy prior to drilling the first deep test in 1951 at Ihno, some 10miles North East of warri in the Delta area, made some intensive geological and geophysical studies from 1946 to 1957. The name Shell D' Arcy was changed to Shell-Bp Petroleum Company on 30$^{th}$ April, 1956.

The first oil show was experienced in Shell D' Arcy's Akata-1 well in 1953 and the first commercial find was made by Shell-Bp in the sediments of the delta complex in late 1955 in the tertiary Agbade formation at Oloibiri. Gas was found at Afam, 21 miles North North East of port-Harcourt in 1956.(API,1941)

Nigeria exported her first oil cargo in 1958 and oil began to produced from the offshore in 1965, from Gulf's Okan field, situated on the Westside of the Niger Delta.

Consequently, over the years, geophysics became a rallying point in exploration, to locate those simple structural traps in the oil province of the Niger delta. The Niger Delta id now at a mature state of exploration and the location of these structural traps is becoming increasingly difficult as a great deal of it have been found (Onuolia; 1987).

The dependence on wire logs cannot be over-emphasized, as it is used to reveal the geology and reservoir properties of oil pools. We should always bear in mind that the logs measure the electrical and other physical properties that are often indirectly related to the reservoir properties.

## Theory

The formation density compensation log is useful for porosity determination, detection of gas, determination of hydrocarbon density, evaluation of shally sands and complex lithologies. It is the most commonly used indicator of the porosity of a formation. A source of high-velocity gamma radiation is pressed against the side of the borehole and the rays are emitted directly into the formation. The log often measures the amount of back scattering of the gamma radiation through collisions with the electrodes in the rock.

The rebuilding is, thus related to the true electron density, which in turn is inversely related to the porosity.

$$\varphi = \frac{\rho_m - \rho_b}{\rho_m - \rho_f} \text{------------------------} 1$$

Where

φ = Porosity

$\rho_m$ = apparent matrix, $\rho_b$ = bulk density $\rho_f$ = mud filtrate density in g/cm$^3$.

Archie (1950), defined petrophysics as the physics of individual rocks in relations to their petrology, and this offers a viable tool in oil exploration. Some of the essential petrophysical parameters needed to evaluate a reservoir include porosity, Lithology and reservoir thickness, water saturation, index of oil morability, hydrocarbon saturation bulk oil volume, etc. (Schlumberger,1974)

Porosity is the percentage of voids in a given volume of rock. It is the pore volume per unit volume of formation. It is the most important attribute of a reservoir rock because it determines the amount of fluid it can hold. Id the rock type and its matrix density are known, the porosity can be calculated from the bulk density as:

$$\varphi = \frac{\rho_{matrix} - \rho_{bulk}}{\rho_{matrix} - \rho_{fluid}} \text{-------------} 2$$

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For the purpose of this study, porosity will be determined as an arithmetic average of the density porosity (φ B) and the neutron porosity (φ N).

$$\varphi B = \frac{\rho_{ma-\rho_b}}{\rho_{ma-\rho_f}} - - - - - 3$$

Where

$\rho_{ma}$ =matrix density

$\rho_f$ = fluid

Schlunberger (1994) gave the following values

$\rho_{ma}$ = 2.65g/cm$^3$ for sand stones

$\rho_{ma}$ = 2.71g/cm$^3$ for limestone

$\rho_{ma}$ = 2.87g/cm$^3$ for dolomite

Archie (1942), proposed the formula:

a/ $\varphi^m$

Where, F=formation factor

M=Cementation factor

a = Constant

φ =Porosity

Values of a and n are constant for different lithologies and in the case of Niger Delta, they are generally taken as 0.62 and 2.15 respectively.

Water saturation is the percentage of pore volume in a rock, which is occupied by the formation waters and is given as:

$$S_w = \frac{\left(\frac{a}{\varphi^m} \cdot \frac{R_W}{R_t}\right)^{\frac{1}{2}}}{\sqrt{\frac{FW}{R_t}}}$$

Where,

$S_w$ =water saturation

N= saturation

Fw =$R_o$ when the formation is 100% ater saturated

$Sw^n$ = $R_o/R_t$

$$S_w = \sqrt{\frac{R_o}{R_t}} = \sqrt{\frac{Fw}{R_t}} \text{-------------------------5}$$

The flushed zone water saturated is the amount od water in the zone affected by mud invasion.

Schlumberger (1974) derivd the expression for Sxo as:

$$S_{xo} = S_w^{\ 1/5} \text{ ---------------------------------- } 6$$

Where

$$S_w = \frac{\left(\frac{R_{xo}}{R_t}\right)^{\frac{5}{8}}}{\frac{R_{mt}}{R_w}} = \sqrt{\frac{Fw}{R_t}}$$

Hydrocarbon saturation is the fraction of the pore volume filled with hydrocarbons. It is estimated between water saturation and gas unity. The oil gas (hydrocarbon saturation) can be expressed as:

$$S_h = 1 - S_w \text{ ----------------------------------------------- } 7$$

If the water saturation of a reservoir is 100%, it implies hydrocarbon absent.

The residual hydrocarbon saturation ($S_{hr}$) is the amount of hydrocarbon left in the flushed zone after the water saturation has been determined.

Mathematically,

$$S_{hr} = 1 - S_{xo} \text{ ----------------------------------------- } 8$$

Where,

$S_{xo}$ = water saturation of the flushed zone index of oil movability is defined as the ratio of water saturation to the flushed zone water saturation ($S_{xo}$)

$$1.0M - \frac{S_w}{S_{xo}} \text{-------------------------------------9}$$

Conventionally, 1.0.M is 1 or approximately so, it implies that no hydrocarbon have been flushed by the invasion where as movable hydrocarbon are indicated when 1.0.M < 0.7

When 1.0.M > 0.7, it indicates immovable hydrocarbon.

The bulk volume oil (B.V.O) is the percentage of the expressed mathematically as:

$$B.V.O = (S_{xo} - S_w)\ \varphi$$

If B.V.O = 1 or within its range, it implies that the volume of the reservoir with immovable hydrocarbon is very minimal.

Therefore, the resistively of the formation water (Rw) for Koko well two was determined, using the formula below.

$$SP = k\log\frac{R_{mf}}{R_w} \text{ ---------------------------10}$$

$$SP = -k\log\frac{R_{mf}}{Sp} \text{ --------------------------11}$$

Where,

Sp = voltage difference between shale and sand stone in millivolt.

K = a constant, for Nacl solutions, K = 71 at 25°C or (77°F)

$R_{mf}$ = resistively of mud filtrate in $R_m$

$R_w$ = resistively of formation water in $R_m$

**Stratigraphy of the Studied Area**

The Well 2 of Koko field occur at the Northern end in the Niger Delta of Nigeria It is located about 70km North East of Warri, between longitude 5.4$^0$ and latitude 5. 5$^0$N. And Longitude 6.3$^0$ to 6.7$^0$ E.The proto deltas developed in the northern part of the basin during capanian transgression and ended with the poleocene transgression. It has been suggested that formation of the modern delta basin which enhanced and controlled the development of the present day Niger delta, developed by rift faulting during the precambrian. Sedimentological and funal data suggest that the modern Niger delta has a configuration similar to that of the past. (C.A Kogbe al, 1975)

**Data Acquisition**

The log data used for this study were acquired by interdrill between 1999 and 2000 for Shell Petroleum Development Company, Warri. The data were acquired with modernized digital electronics, which consist of the sensors, the cable, the cable telemetry and the signal processor. With the use of digital telemetry, there was enormous increase in he data rate that were being handled by the logging cable digital recording within the logging unit and this in turn increased the record capacity. The use of the digitalized system also facilitated the transmissions of the log signal to computing centres or base offices.

The well was drilled as an exploratory well and various analytical tests aimed at defining the petrophysical characteristics of the reservoir sand, were utilized in the evaluation of the hydrocarbon prospect of the area. The log provided include the gamma ray log, the resistivity/conductivity logs, the compensated neutron log (CNL) and the focused density compensated log (FDC). Which were used in getting information on the well through the identification of the various lithologic units present in the well.

The processing signal was performed for at least three levels. The uphole in the truck, the downhole at a central processing centre. The raw data were processed downhole and the processed signals transmitted to the surface. A well site computer system, called cyber service unit (CSU) is now standard on Schlumberger units through out the world. The system provided the capabilities to handle large amounts of data. It solved the many problems posed by past limitation of combination logging systems (the stacking or combination of many tool stings). The CSU system provided the clear potential for well site processing of data. Nearly all the common log interpretation models and equations were executed on the CSU. Evaluation programmes ranged in scope from single well evaluation program to a series of special application products to reservoir description services that was used in evaluating the entire field.

The materials used for the well logging of Koko well-2 include drilling bit, electrodes, mud, motor, jar, panel cartage and heavy weight drilling pipe (HWDP). The type of drilling mud used was the salt based drilling mud. The size of the drilling bit were 16 inches, 12.25 inches and 8.5 inches. The table below shows the other parameters used in logging Koko well-2.

R-mud = Resistively of mud
$R\text{-}m_c$ = Resistively of mud cake
$R\text{-}m_f$ = Resistively of mud filtrate
T-mud = Temperature of mud
$T\text{-}m_c$ = Temperature of mud cake
$T\text{-}m_f$ = Temperature of mud filtrate
BHT = Bottom Hole Temperature.

**Result and Discussion**

The analysis of the various wireline logs provided, were based on the several petrophysical parameters read directly from the logs and in other cases a comprehensive computation using the formula earlier stated in equation 11 was done.

Table below shows the general lithological units found in the Koko well-2 and gives the probable hydrocarbon bearing internals and quantitative evaluation from wireline logs of Koko well-2 field.

**Conclusion**

The reservoir-bearing sands in the well have moderate to high resistivity values indicating either salt water or fresh water filling the pores. Nevertheless, light constituent of hydrocarbon in contact with salt water of fresh water was observed.

Quantitative analysis based on the resistivity/conductivity log, compensated neutron log (CNL), formation density compensation log (FDC) revealed that the hydrocarbon prospect in Koko field is low and therefore, more exploration should be carried out.

This inference is based on the values obtained from the determination of hydrocarbon saturation, bulk volume oil (B.V.O), bulk volume ware, index of oil movability and formation factor.

Therefore, the hydrocarbon prospect in Koko well two is low at the present depth of investigation.

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**Drilling parameter used in logging Koko well-2**

| Date drilled | Mud type | R-mud $R_m$ | T-mud $^oF$ | $R\text{-}m_c$ $R_m$ | $T\text{-}m_c$ $^oF$ | R-mf $R_m$ | $T\text{-}m_f$ $^oF$ | BTH |
|---|---|---|---|---|---|---|---|---|
| Jan, 1999 | BENTONITE & CMC | 1.4 | 75 | 1.71 | 75 | 1.25 | 75 | $175^oF$ |

**Portable hydrocarbon bearing intervals and quantitative Potential evaluation from wireline log of well-2 of Koko**

| | | POROSITY | | | FORMATION WATER | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH INTERVAL (FLAH) | F | øD | N | AV | RESISTIVITY ($R_w$) | Sw | Sh | Sxo | Shr | Mos | IOM | BVW | BVO |
| 5210.0-571 | 8.25 | 30 | 30 | | | 0.74 | 0.26 | 0.94 | 0.06 | 0.20 | 0.79 | 22.2 | 6 |
| 5274-5281 | 7.43 | 28 | 35 | 31.5 | | 0.99 | 0.01 | 0.99 | 0.01 | - | 1 | 312 | - |
| 5281-5330 | 10.65 | 87.3 | 26 | 26.6 | 1.32 | 0.40 | 0.60 | 0.83 | 0.17 | 0.43 | 0.48 | 10.66 | 11.44 |
| 5330-5350 | 8.16 | 33.3 | 27 | 30.2 | | 0.60 | 0.40 | 0.90 | 0.10 | 0.30 | 0.67 | 18.12 | 9.06 |
| 5350-5362 | 16.6 | 27.3 | 16 | 21.65 | | 0.65 | 0.35 | 0.92 | 0.08 | 0.27 | 0.71 | 14.1 | 5.85 |
| 5362-5372 | 24.3 | 13.3 | 23 | 18.2 | | 103 | 0.03 | 101 | 0.01 | 0.02 | 102 | 18.75 | 0.36 |
| 5372-5409 | 13.8 | 21.2 | 26 | 23.6 | | 0.06 | 0.33 | 0.92 | 0.08 | 0.25 | 0.73 | 15.8 | 5.9 |
| 5409-5415 | 9.8 | 30.3 | 25 | 27.5 | | 0.66 | 0.33 | 0.92 | 0.08 | 0.25 | 0.72 | 18.2 | 7.2 |
| 5415-5450 | 13.6 | 20.6 | 27 | 23.8 | | 0.67 | 0.33 | 0.92 | 0.08 | 0.25 | 0.73 | 15.2 | 7.2 |
| 5450-5464 | 540 | 26 | 47 | 365 | | 115 | 0 15 | 1 03 | 0 03 | 0 12 | 1 12 | 119 | 438 |
| 5464-5475 | 762 | 27.3 | 35 | 311 | | 098 | 002 | 099 | 001 | 001 | 099 | 305 | 031 |
| 5475-5592 | 913 | 242 | 33 | 286 | | 055 | 045 | 089 | 011 | 034 | 062 | 157 | 97 |
| 5592-5598 | 1345 | 24.8 | 23 | 239 | | 067 | 0.33 | 0.92 | 0.08 | 025 | 073 | 100 | 59 |
| 5598-5734 | 7.65 | 15.2 | 47 | 3.11 | | 0.50 | 0.50 | 0.87 | 0.13 | 0.37 | 0.57 | 15.5 | 11.5 |
| 5734-5770 | 12.6 | 27.3 | 22 | 24.6 | | 1.26 | 0.26 | 1.05 | 0.05 | 0.01 | 12 | 13.9 | 52 |
| 5770-5794 | 11.6 | 18.2 | 33 | 25.6 | | 0.92 | 0.82 | 0.98 | 0.02 | 0.06 | 0.94 | 23.6 | 15.1 |
| 5794-5800 | 7.26 | 26.7 | 37 | 31.8 | | 1.03 | 0.03 | 1.01 | 001 | 0.02 | 1.02 | 32.7 | 064 |
| 5800-5910 | 18.2 | 17.5 | 24 | 20.78 | | 0.98 | 0.02 | 0.99 | 001 | 001 | 099 | 204 | 021 |
| 5910-5920 | 52 | 27.3 | 47 | 371 | | 0.99 | 0.01 | 099 | 001 | | | 367 | |
| 5920-5941 | 218 | 15.2 | 23 | 191 | | 126 | 0.26 | 105 | 005 | 024 | 120 | 24.1 | 401 |
| 5941-5948 | 7.12 | 27.3 | 37 | 32 1 | | 0.38 | 0.62 | 0.82 | 0 18 | 0.44 | 0 46 | 43 4 | 14 1 |
| 5948-6002 | 21 8 | 15.0 | 23 | 19 0 | | 1 65 | 0.65 | 1 11 | 0 11 | 0 54 | 14 | 544 | 10 3 |
| 6002-6025 | 52 | 27.3 | 47 | 37 1 | | 1.17 | 0.17 | 103 | 003 | 044 | 11 | 434 | 52 |
| 6025-6069 | 196 | 15.2 | 25 | 20 | | 1.60 | 0.60 | 1.09 | 009 | 0.51 | 14 | 20 | 102 |
| 6069-6100 | 6 84 | 28 | 37 | 32 7 | | 1 02 | 006 | 101 | 001 | 0.05 | 1 05 | 310 | 101 |
| 6100-6119 | 218 | 15 | 23 | 191 | | 1.65 | 0.65 | 111 | 011 | 0.54 | 14 | 315 | 103 |
| 6119-6130 | 10.6 | 16.4 | 37 | 26.7 | | 1 47 | 0.47 | 108 | 0.08 | 0.39 | 1.36 | 392 | 94 |
| 6130-6159 | 14.46 | 21.2 | 25 | 23.1 | | 1 35 | 0.35 | 1 06 | 0.06 | 0.29 | 1 27 | 32 | 67 |
| 6159-6169 | 72 | 16.96 | 47 | 31.9 | | 1.17 | 0 17 | 1 03 | 0.03 | 0.14 | 11 | 37.4 | 45 |
| 6169-6218 | 120 | 27.3 | 23 | 25 | | 0 75 | 0.25 | 0.94 | 0.06 | 0.19 | 0.79 | 1875 | 4 25 |
| 6218-6260 | 95 | 21.2 | 35 | 28.1 | | 1 25 | 0.25 | 1 05 | 0.05 | 0 20 | 119 | 351 | 425 |
| 6260-6363 | 9 12 | 27.3 | 30 | 28 6 | | 1 07 | 0 07 | 1 01 | 0 01 | 0.06 | 1 06 | 30 6 | 1 72 |

**Lithological Identification from wireline log analysis of well 2 of Koko**

| Depth | Sp log | GR log | CAL log | Resistivity log (Ohm-m) | | | Neutron log | Density log | Lithology |
|---|---|---|---|---|---|---|---|---|---|
| Interval (Ft) | (Millivolt) | APL | IN | MSFL ($R_{xo}$) | LLS | LLD ($R_t$) | Fraction | G/CC | |
| 5210-5274 | 90 | 32 | 12.8 | 1.5 | 7 | 20 | 0.30 | 2.15 | Sand |
| 5274-5281 | 42 | 74 | 14.2 | 2 | 4.2 | 10 | 0.35 | 2.18 | Shale |
| 5281-5330 | 78 | 29 | 12.6 | 2 | 10 | 85 | 0.26 | 2.2 | Shale |
| 5330-3350 | 82 | 64 | 14.2 | 2 | 6 | 30 | 0.27 | 2.1 | Shale |
| 5350-5362 | 28 | 36 | 14.5 | 3.5 | 9 | 52 | 0.16 | 2.2 | Sand |
| 5362-5372 | 45 | 75 | 140 | 10 | 10 | 30 | 0.23 | 2.43 | Shale |
| 5372-5409 | 90 | 33 | 15.0 | 2 | 9 | 40 | 0.26 | 2.3 | Sand |
| 5415-5450 | 38 | 28 | 14.1 | 3 | 7 | 40 | 0.27 | 2.31 | Sand |
| 5450-5464 | 54 | 95 | 14.5 | 2 | 3 | 6 | 0.47 | 2.22 | Shale |
| 5464-5475 | 86 | 50 | 14.2 | 2 | 6 | 10.5 | 0.35 | 2.20 | Sand |
| 5475-5592 | 38 | 30 | 14.8 | 3 | 8 | 40 | 0.33 | 2.25 | Shale |
| 5592-5598 | 52 | 90 | 14.7 | 3 | 4 | 7 | 0.23 | 2.24 | Sand |
| 5598-5734 | 80 | 28 | 13.4 | 2 | 9 | 40 | 0.47 | 2.40 | Shale |
| 5734-5770 | 28 | 100 | 14.9 | 3 | 7 | 10.5 | 0.22 | 2.20 | Sand |
| 5770-5794 | 94 | 45 | 13.7 | 2 | 4 | 18 | 0.33 | 2.35 | Shale |
| 5794-5800 | 42 | 98 | 12.6 | 3.5 | 5 | 9 | 0.37 | 2.21 | Sand |
| 5800-5910 | 78 | 33 | 13.8 | 2 | 4 | 25 | 0.24 | 2.36 | Shale |
| 5910-5920 | 48 | 100 | 12.4 | 3 | 4 | 7 | 0.47 | 2.20 | Sand |
| 5920-5941 | 74 | 30 | 12.8 | 2 | 8 | 18 | 0.23 | 2.40 | Shale |
| 5941-5948 | 45 | 94 | 12.4 | 8 | 8 | 25 | 0.37 | 2.20 | Sand |
| 5948-6002 | 28 | 32 | 14.8 | 3 | 7 | 10.5 | 0.23 | 2.58 | Shale |
| 6002-6025 | 40 | 90 | 12.8 | 1.5 | 3.5 | 5 | 0.47 | 2.20 | Sand |
| 6025-6069 | 35 | 27 | 12.6 | 1.5 | 4.5 | 10 | 0.25 | 2.40 | Shale |
| 6069-6100 | 42 | 110 | 13.0 | 2 | 6.0 | 8 | 0.37 | 2.18 | Sand |
| 6100-6119 | 30 | 33 | 12.2 | 2 | 5 | 10.5 | 0.23 | 2.40 | Shale |
| 6119-6130 | 32 | 121 | 14.2 | 3 | 5 | 0.5 | 0.37 | 2.34 | Sandy shale |
| 6130-6159 | 70 | 30 | 14.8 | 2 | 5.5 | 10.5 | 0.25 | 2.30 | Shale |
| 6159-6169 | 48 | 100 | 12.0 | 3 | 5 | 7 | 0.47 | 2.37 | Sandy shale |
| 6169-6218 | 78 | 28 | 14.2 | 1.7 | 10 | 28 | 0.23 | 2.20 | Shale |
| 6218-6260 | 18 | 34 | 15.0 | 3 | 5 | 8 | 0.35 | 2.30 | Sandy shale |
| 6260-6363 | 62 | 28 | 13.8 | 2 | 5 | 10.5 | 0.30 | 2.20 | Shale inter bedded with sand |