International Journal of Applied
and Natural Sciences (IJANS)
ISSN(P): 2319-4014; ISSN(E): 2319-4022
Vol. 4, Issue 5, Aug - Sep 2015, 55-64

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

HYDROCARBON RESERVOIR CHARACTERIZATION USING WELL LOG IN NIGER DELTA BASIN OF NIGERIA

O. I. HORSFALL, D. H. DAVIES & O. A. DAVIES

Department of Physics, Rivers State University of Science and Technology, 500001, Port Harcourt Nigeria

ABSTRACT

A study for the characterization of hydrocarbon reservoirs using well logs have been carried out in the Niger Delta in order to evaluate the field's hydrocarbon prospectivity, delineate hydrocarbon and water bearing zones and petrophysical properties of the hydrocarbon reservoirs of interest. Data from four composite well logs comprising of gamma ray, resistivity, neutron, density logs were used for the study. Gamma ray log was used for lithology differentiation, Resistivity log was used to identify form the response of resistivities of various zones. High resistivity signifies hydrocarbon bearing zone while low resistivity value indicates shaley zones. The combined density and neutron logs was used for the identification and differentiation of the various fluids in the sections. The results from the study showed that nine out of the twenty-two zones of interest (sand bodies) was delineated and correlated across for possible identification of hydrocarbon, and were identified as potential hydrocarbon reservoirs. Also the result indicates that there is an increase in porosity with an increase in permeability. The evaluated petrophysical parameter indicated that porosity ranges between (18-31%), water saturation (14-44%), hydrocarbon saturation (56-86%), permeability (138-10662)

KEYWORDS: Reservoir, Well Log, Petrophysical Properties

INTRODUCTION

The principal goal of the upstream petroleum industries is to produce hydrocarbons with a sustained minimal cost. As a result, proper planning, delineation and development of reservoirs become very necessary and challenging as the demand for maximum possible turnover and returns of investment becomes more challenging in a high cost industry with increasing competition and technological advancement and demand. Accurately simulating field performance however, requires the knowledge of petrophysical properties throughout the life of a reservoir.

Reservoir characterization can be defined as all the germane and valuable information requisite for the effective description of a reservoir(Chopra & Michelena, 2011). The reservoir, by this implication, is thus defined in terms of its capacity to store and produce hydrocarbons. It becomes necessary therefore, to know the complete reservoir architecture of the reservoir which includes the internal and external geometry, its model, as well as the distribution of the reservoir properties. These reservoir properties are classified into two groups, viz.: static (such as porosity, permeability, heterogeneity, net pay, and thickness) and dynamic (fluid flow within the reservoir). Such information about the reservoir will help improve production rates, rejuvenate oil fields, predict future reservoir performance, minimize costly expenditure, and help management of oil companies to draw up accurate financial models(Ameloko & Omali, 2013). Reservoir characterization is an important phase between the discovery of an oil or gas field and the reservoir management phase. Reservoir characterization an interdisciplinary measure which integrates the application of geology, geophysics, reservoir engineering, petrophysics, economics, and data management. The success of reservoir characterization depends on the proper integration, management and application of these disciplines, an elusive goal in some cases. The reservoir characterization exercise usually begins with the available geological information and knowledge about the depositional and facies environment. Reservoir characteristics such as natural heterogeneity, spatial variability of permeability and porosity, porous media properties and spatial distribution of hydrocarbon and water predominantly control the flow field, reservoir performance, development strategies, and hence the economic returns ofinvestments, which is the primary concernof the oil companies. The characterization of reservoirs therefore, require the integration of different types of data in order to adequately define the reservoir model.

GEOLOGY OF THE STUDY AREA

The study area falls within the Niger Delta Basin of Nigeria. The Niger Delta basin lies between latitudes 3^{O}N and 6^{O}N, and longitudes 5^{O}E and 8^{O}E, in the Gulf of Guinea in equatorial West Africa (Southern Nigeria), forming one of the world's most productive hydrocarbon province. Extensive details of the Niger Delta was given by (Short & Stauble, 1967). The Niger delta basin is divided into mainly three lithostratigraphic units, the Akata (Paleocene to Recent), Agbada (Eocene to Recent) and the Benin (Oligocene to Recent) Formations which conforms with a lower pro-delta lithofacies, a middle delta front lithofacies and an upper delta top facies respectively (Aigbedion & Aigbedion, 2011; Ajaegwu, Odoh, Akpunonu, Obiadi, & Anakwuba, 2012). These researches have shown that the Akata formation which is comprised mainly of marine shale with sandy and silty beds laid down as turbidites and continental slope channel fills, about 7000 meters in thickness, serves as the source rock; the Agbada formation on the other hand which is over 3700 meters thick is the main hydrocarbon bearing unit consisting mainly of sandstone at the top with shaley intercalations and predominantly shale with sandstone intercalations at the lower part; finally the Benin formation which is about 2100 meters, is composed of continental sands and gravels and is the main groundwater bearing formation in the Niger Delta basin.

METHODOLOGY

Four suits of composite well logs NWKP-1, NWKP-2, NWKP-3, and NWKP-4 respectively, obtained from Shell Petroleum Development Company of Nigeria (SPDC) was used for this study. See Figure 0.1 and Figure 0.2. The well logs consists of Gamma ray, resistivity, and neutron and density logs. These logs are used to evaluate and analyze the petrophysical properties such as hydrocarbon saturation(S_h), porosity(Φ), permeability(K), water saturation(S_w), water resistivity(R_W), etc. The evaluation of these properties is stated below.

Lithology Identification

The evaluation of the petrophysical properties starts with identifying the economic zones (i.e clean sand with sizable quantity of hydrocarbons).

The lithologies (sandstone and shale) were identified using the gamma ray log with reference to sand/shale baseline. The percentage sand/shale is computed from the gamma ray log using the equation below

The % (shale/sand) is computed from the gamma ray log as:

$$\%\text{Shale} = \left(\frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}\right) x100 \qquad 1$$

Where,

%shale = Percentage volume of shale in the formation

GR_{log} = Gamma Ray Log Reading

GR_{max} = Gamma Ray Log Reading in Shale Zone

GR_{min} =Gamma Ray Log Reading in clean Sand Zone.

From the above equation,

%sand =100% - %shale 2

Lithological presumptions are made based on which percentage is greater than or equal to 50%

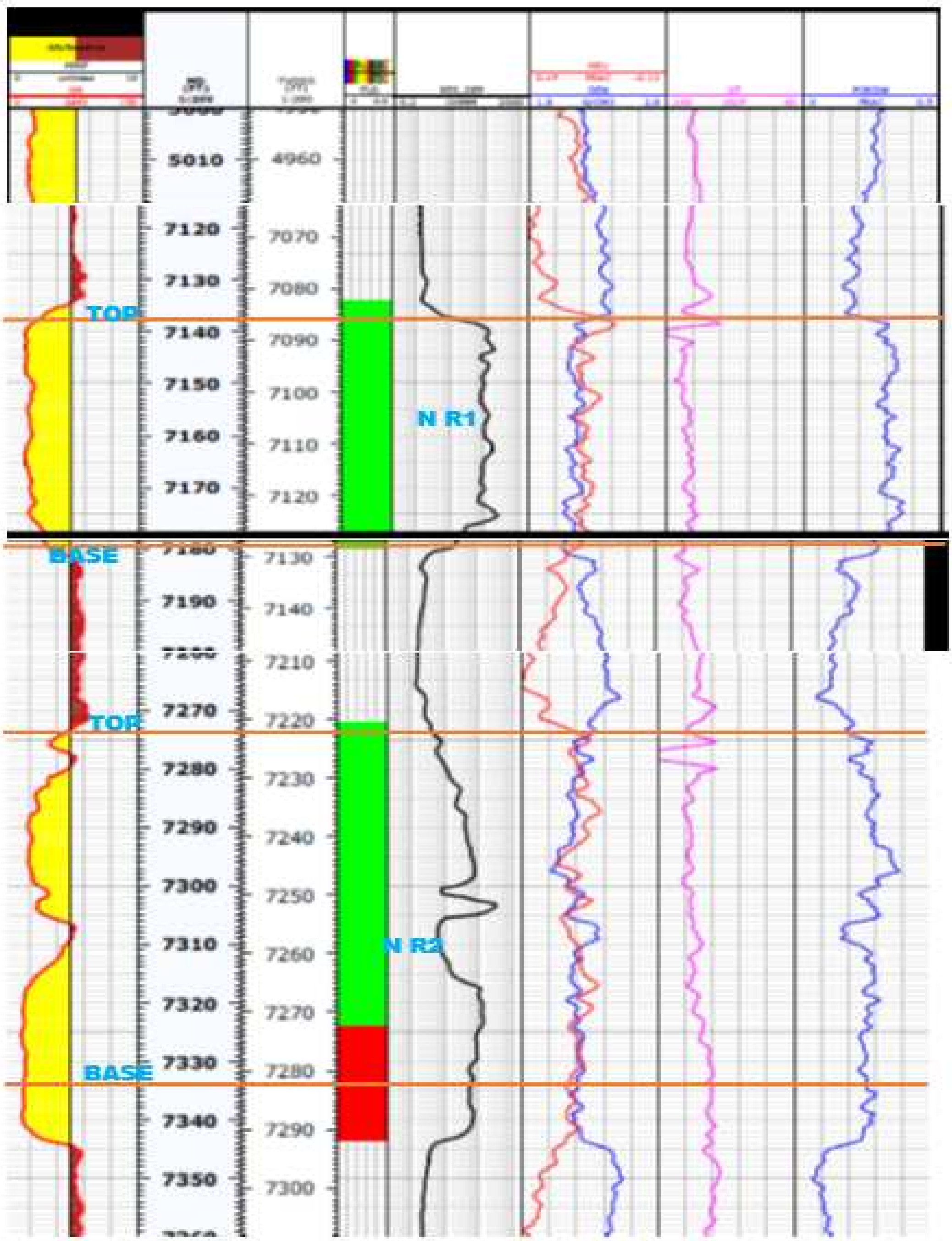

Figure 1: Composite Log of Well NWKP-2

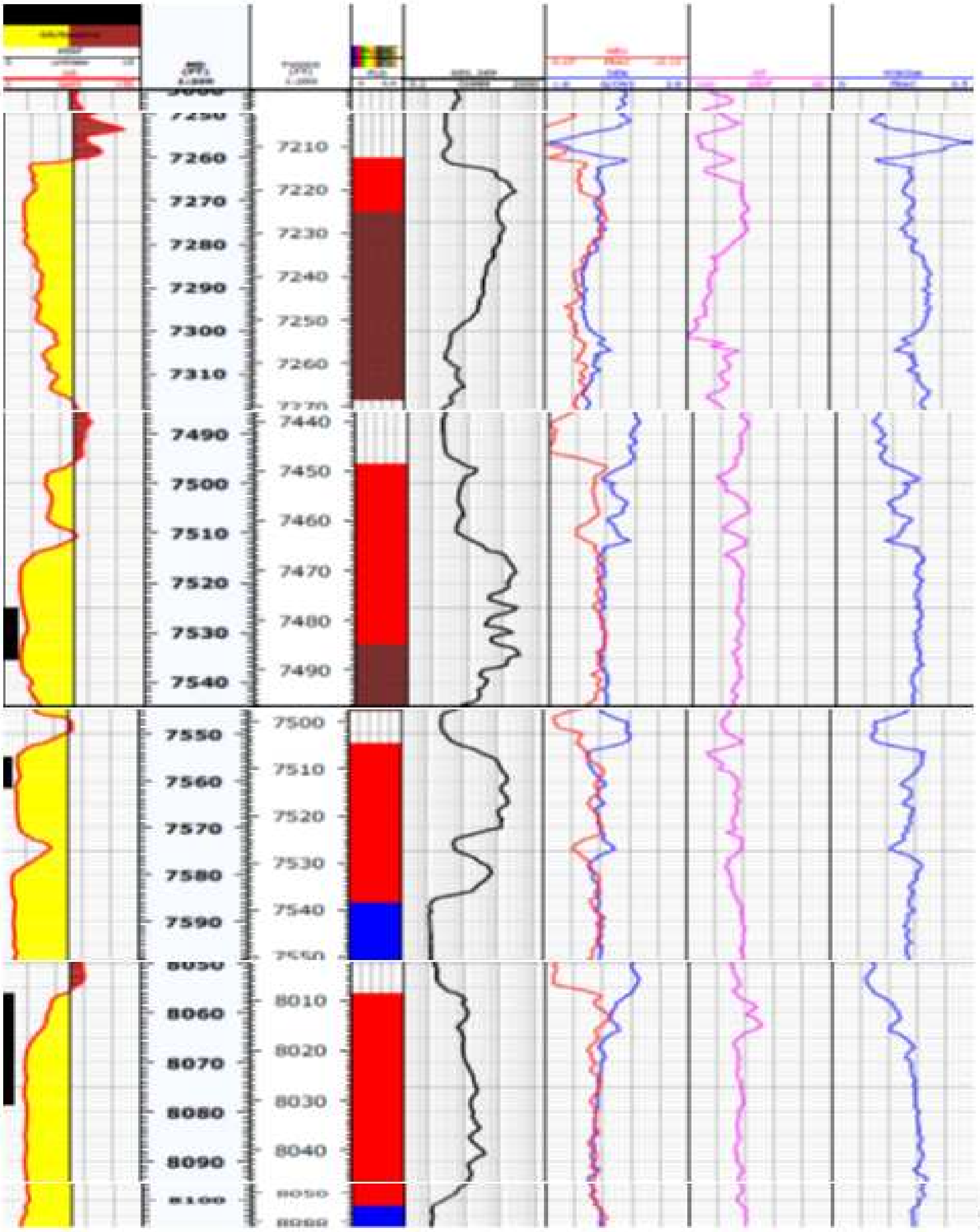

Figure 2: Composite Log of Well NWKP-4

Hydrocarbon and Non-hydrocarbon Bearing Zones

The combined density and neutron log was used for the identification and characterization of the various fluids in the formation, i.e. hydrocarbon from non-hydrocarbon bearing zones, Gas zones are identified from the balloon effect (cross over) of the neutron and density logs. The resistivity log was also used to identify the fluids. In this regards, zones of possible oil accumulations is indicated by high resistivity values whereas water zones have low resistivities.

Porosity (Φ%)Estimation

The porosity used in this study was computed from the density log. The density log records the formation's bulk density which is the overall density of a rock including the solid matrix and the fluid enclosed in the pores(Horsfall, Omubo-Pepple, & Tamunobereton-ari, 2013). Density logging is based on the physical phenomenon of gamma ray scattering as a function of the bulk density of an environment irradiated by a gamma ray source. The density log can be used quantitatively, to calculate porosity and indirectly to determine hydrocarbon density. It is also useful in calculation of acoustic impedance. Qualitatively, it is useful as a Lithology indicator, as well as identification of certain minerals, assessment of source rock organic matter content and identification of overpressure and fracture porosity(Horsfall et al., 2013). The formation bulk density is related to formation matrix density(ρ_{ma}) and formation fluid density (ρ_f) by:

$$\rho_b = (1 - \Phi_d)\rho_{ma} + \Phi_d\rho_f \quad 3$$

Rearranging eq. 3

$$\Phi_d = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad \text{(Dresser, 1979)} \quad 4$$

Where

Φ_d =Porosity derived porosity

ρ_{ma} =Matrix (or grain) density = 2.65g/cm^3 for sandstone

ρ_b =Bulk density from log

ρ_f =Fluid density (either oil or gas); ρ_f = 0.85 for oil and 0.2 for gas

Formation Resistivity Factor (FRF)

The formation Resistivity Factor (FRF) also called the formation factor (F) was computed using Archies Formula

$$F = a/\Phi^m \quad 5$$

Where

a = constant related to texture, (assumed to be approximately 1 for sandstone)(Rider, 2002).

m = cementation factor $(2 \leq m \geq 1.3)$, According to Mavko, Mukerji, and Dvorkin (2009)

Φ = total porosity

Permeability Estimation (*K*)

Various models have been proposed over the years relating the permeability of a rock to it'sporosity, Φ, and irreducible water saturation, S_{wir}, as obtainable from wireline logs. According toTixier (1949),

$$K = \left[\frac{250 \times \Phi^3}{S_{wir}}\right]^2 \quad 6$$

Where,

S_{wir} =Irreducible water saturation

Φ = Total porosity

The irreducible water saturation S_{wir}may be derived using the Schlumberger approach. In the zone ofS_{wir}, the hydrocarbon produced is water free. S_{wir} is defined mathematically as

$S_{wir} = \left(F/_{2000}\right)^{\frac{1}{2}}$ (Dewan, 1983) 7

Where,

F = Formation factor

Water Resistivity(R_w)

To calculate water saturation, S_w the method used in this study requires a water resistivity, $R_w$value at formation temperature calculated from the porosity and resistivity logs within clean water zone, using the R_o method given by the following equation

$R_w = {R_o}/_{F}$ 8

Where,

R_0 =Deep resistivity values in the water zone

F = Formation factor

Water Saturation, (S_w)

Water saturation,(S_w**)** can then be calculated using Archie's method:

$S_w = \sqrt[n]{FR_w/_{R_t}}$ 9

Where,

R_t =True formation resistivity

R_w =Water resistivity

n =Saturation exponent S_w =Water saturation

F =Formation factor

Hydrocarbon Saturation (S_h)

Hydrocarbon Saturation, (S_h)is the percentage of pore volume in a formation occupied by hydrocarbons. It can be determined by subtracting the value obtained for water saturation from 100% i.e.

$S_h = (100 - S_w)\%$ 10

Where,

S_h =Water Saturation

Net/Gross Reservoir Thickness

The gross reservoir thickness H, was determined by looking at tops and bases of the reservoir sands across the well. The net thickness which is the thickness of the reservoir was determined by defining basis for non-reservoir and reservoir sands using the gamma ray log. This was carried out by drawing a shale baseline and sand baseline on the gamma ray log. The thicknesses of the shale, h_{shale} within the reservoir sands were obtained and thereafter subtracted from the gross reservoir thickness. Hence, net reservoir thicknesswas obtained for all the reservoirs in the well thus:

$$h = H - h_{shale} \tag{11}$$

$$Net/Gross = h/H \tag{12}$$

Where

H =Gross reservoir thickness

h =Net reservoir thickness

h_{shale} =Shale thickness

RESULTS AND DISCUSSIONS

A detailed characterization of the hydrocarbon reservoirs in the formation of interest for analyzing the petrophysical properties using the various methods is presented and in the following tables.

Table 0.1: Summary of Computed Petrophysical Parameters from Well NKWP-1

Reservoir Name	Top (MD) Ft(m)	Bottom (MD) Ft(m)	Gross Thickness Ft(m)	Net Thickness Ft(m)	Net/Gross Thickness Ft(m)	Φ frac.	S_w frac.	S_h frac.
NR2	7155(2188)	7174(2181)	39(12)	33.7(10.2)	0.86	0.31	0.24	0.76
NR5	10551(3216)	10608(3233)	57(17)	45(13.7)	0.79	0.20	0.20	0.80

Table 0.2: Summary of Computed Petrophysical Parameters of Well NKWP-2

Reservoir Name	Top (MD) Ft(m)	Bottom (MD) Ft(m)	Gross Thickness Ft(m)	Net Thickness Ft(m)	Net/Gross Thickness Ft(m)	Φ frac.	S_w frac.	S_h frac.
NR1	7138(2176)	7179(2188)	41(12)	36(11)	0.88	0.20	0.16	0.84
NR2	7276(2218)	7343(2238)	67(20)	62(19)	0.93	0.18	0.14	0.86

Table 0.3: Summary of Computed Petrophysical Parameters of well NKWP-3

Reservoir Name	Top (MD) Ft(m)	Bottom(MD) Ft(m)	Gross Thickness Ft(m)	Net Thickness Ft(m)	Net/Gross Thickness Ft(m)	Φ frac.	S_w frac.	S_h frac.
NR1	7116(2169)	7160(2182)	44(13)	35(11)	0.80	0.25	0.30	0.70
NR5	9023(2750)	9059(2761)	36(11)	32(10)	0.88	0.25	0.15	0.85

Table 0.4: Summary of Computed Petrophysical parameters of well NKWP-4

Reservoir Name	Top (MD) Ft(m)	Bottom(MD) Ft(m)	Gross Thickness Ft(m)	Net Thickness Ft(m)	Net/Gross Thickness Ft(m)	Φ frac.	S_w frac	S_h frac
NR1	7262(2213)	7298(2224)	36(11)	30(9.14)	0.83	0.28	0.21	0.79
NR2	7514(2290)	7584(2312)	70(21)	66(20)	0.94	0.27	0.15	0.85
NR3	8057(2456)	8095(2467)	38(12)	30(9)	0.79	0.23	0.44	0.56

Table 0.5: Summary of Computed Petrophysical Parameters of all the well

Reservoir Name	Porosity Φ%	Formation Factor F	Permeability K (*md*)
NR2 of well NWKP-1	31	10	10662
NR5 of well NWKP-1	20	25	320
NR1 of well NWKP-2	20	25	320
NR2 of well NWKP-2	18	31	138
NR1 of well NWKP-3	25	16	1907
NR5 of well NWKP-3	25	16	1907
NR1 of well NWKP-4	28	13	4636
NR2 of well NWKP-4	27	14	3459
NR3 of well NWKP-4	23	19	979

Table 4.1 shows the summary of the petrophysical parameters of well NWKP-1, which was delineated to contain seven reservoirs, but only two were identified as a hydrocarbon-bearing with porosity ranging from 0.20 to 0.31, water saturation 0.20 to 0.24 and hydrocarbon saturation 0.76 to 0.80, this also depicts that both porosity and water saturation decreases with an increasing depth while hydrocarbon saturation increases with an increase in depth. The reservoirs contain oil.

Table 4.2 shows the summary of the petrophysical parameters of well NWKP-2, which was delineated to contain five reservoirs, but only two were identified as a hydrocarbon-bearing with porosity ranging from 0.18 to 0.20, water saturation 0.14 to 0.16 and hydrocarbon saturation 0.84 to 0.86, it also shows that both porosity and water saturation decreases as the depth increases, while hydrocarbon saturation increases as the depth also increases. The reservoirs which contains gas has the highest percentage of hydrocarbon presence (86%).

Table 4.3 shows the summary of the petrophysical parameters of well NWKP-3, which was delineated to contain six reservoirs, only two that were identified as a hydrocarbon-bearing with porosity which was found to be approximately constant (0.25), water saturation varies from 0.15 to 0.30 and hydrocarbon saturation 0.70 to 0.85, the result indicates that water saturation decreases with an increase in depth while hydrocarbon saturation increases with an increase in depth. The reservoirs contains oil and gas.

Table 4.4 shows the summary of the petrophysical parameters of well NWKP-4, which was delineated to contain four reservoirs, but only three were identified as a hydrocarbon-bearing reservoir with an irregular porosity, water saturation and hydrocarbon saturation profile, NR1 has the highest the percentage of porosity (28%), R3 has the highest water saturation (44%) and NR2 has the highest hydrocarbon saturation (85%). The reservoirs contains oil.

Table 4.5 shows the summary of petrophysical parameters of all the wells, which indicates that high porosity corresponds to high permeability, but with low formation factor. The NR2 of well NWKP-1 having the highest percentage values (31%), NR2 of well NWKP-2 having the highest formation factor (31) and NR2 of well NWKP-1 having the highest permeability values (10663).This also shows that well NWKP-1 has both the highest porosity and permeability.

CONCLUSIONS

The characterization of reservoirs by a detailed petrophysical parameter estimation revealed that the reservoir quality is strongly influenced by the presence of sand bodies as a result of the presence of high values of porosity and permeability. Findings from this study shows that reservoir quality increases with an increase in the values of porosity and permeability. The average water saturation for these reservoirs were estimated to be between (15 – 27) percent, while hydrocarbon saturation falls around (56 – 86) percent. Comparing the results shown between Tables 4.1 to Table 4.4, it is evident that well NWKP-2 has the highest value of hydrocarbon saturation.

ACKNOWLEDGEMENTS

The authors would like to express our appreciation to Shell Petroleum Development Company (SPDC) Rumubiakani, Port Harcourt Nigeria, for providing the suits of well logs and other relevant materials for the purpose of this study.

REFERENCES

1. Aigbedion, I., & Aigbedion, H. O. (2011). Hydrocarbon Volumetric Analysis Using Seismic and Borehole Data over Umoru Field, Niger Delta-Nigeria. *International Journal of Geoscience*, *2*, 179-183.

2. Ajaegwu, N. E., Odoh, B. I., Akpunonu, E. O., Obiadi, I. I., & Anakwuba, E. K. (2012). Late Miocene to Early Pliocene Palynostratigraphy and Palaeoenvironments of ANE-1 Well, Eastern Niger Delta, Nigeria. *Journal of Mining and Geology, 48*(1), 31–43.

3. Ameloko, A., Aduojo , & Omali, A., O. . (2013). Reservoir Characterization and Structural Interpretation of Seismic Profile: A Case Study of Z-Field, Niger Delta, Nigeria. *Petroleum and Coal 55*(1), 37-43.

4. Chopra, S., & Michelena, R. J. (2011). Reservoir characterization. *Society of Exploration Geophysics, 30*(1), 35 - 37.

5. Dewan, J. T. (1983). *Essentials of Modern Open-Hole Log Interpretation*. Tulsa, Oklahoma: Pennwell Corporation.

6. Dresser, A. (1979). *Log Interpretation Charts*. Houston: Dresser Industries, Inc.

7. Horsfall, O. I., Omubo-Pepple, V. B., & Tamunobereton-ari, I. (2013). Correlation Analysis between sonic and density logs for porosity determination in the South-Easter part of the Niger Delta basin of Nigeria. *Asian Journal of Science and Technology, 4*(1), 1-5.

8. Mavko, G., Mukerji, T., & Dvorkin, J. (2009). *The rock physics handbook: Tools for seismic analysis of porous media*: Cambridge university press.

9. Rider, M. H. (2002). *The Geological Interpretation of Well Logs* (2nd Revised ed.). Sutherland, Scotland: Rider-French Consulting Ltd.

10. Short, K. C., & Stauble, A. J. (1967). Outline of Geology of Niger Delta. *American Association of Petroleum Geologist Bulletin, 51*(5), 764-772.

11. Tixier, M. (1949). Evaluation of permeability from electric-log resistivity gradients. *Oil & Gas Journal, 48*(6), 113.