QUANTITATIVE PETROPHYSICAL ANALYSIS AND RESERVOIR STUDIES OF OPA-1 WELL, X-FIELD, NIGER DELTA. NIGERIA

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ABSTRACT

This research work elucidates the application of wireline logs to identify and quantify hydrocarbon reserves and evaluate rock properties in part of the offshore Niger Delta. The petrophysical analyses of the wireline logs provide reservoir characteristics (porosity, permeability and fluids saturation). Quantitative determination of fluid transmissivity (layer thickness times permeability) will be an added advantage to further characterize reservoir rocks. Integrating these two parameters would guide and provide a good knowledge of the potential of porous media and enhance exploration and development of the reservoir rocks.

INTRODUCTION.

The potential and performance of reservoirs depend on both engineering and petrophysical parameters. The engineering parameters are rock compressibility, reservoir storativity, transmissivity, etc, while the fundamental petrophysical parameters are porosity, permeability, and fluid saturation. The relationships among these properties are used to identify and characterize reservoirs.

Reservoir characterization is the continuing process of integrating and interpreting geological, geophysical, petrophysical, fluid and performance data to form a unified, consistent description of a reservoir and produce a geological model that can be used to predict the distribution of reservoir properties throughout the field. It can also be defined as the quantification, integration, reduction and analysis of geological, petrophysical, seismic and engineering data.

LOCATION OF STUDY The field under study is pseudo-named “X’’ field in accordance with the confidentiality agreement of the Oil Company that provided the data. The field is located in the offshore Niger Delta but the co-ordinates of the location of this field were concealed due to proprietary reasons.

NIGER DELTA DEPOBELT

Niger Delta is divided into a number of sedimentary units called depobelt. Depobelts are thought of as transient basinal areas succeeding one another in space and time as the delta prograded southward.

Stacher (1995) showed that the Niger delta sequences consists of a series of discrete depocenter or depobelt which were the main belts of deposition of the Agbada Formation that succeeded each other progressively as the delta shifted its loci downdip through time.

Each depobelt is a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward by large counter regional faults or growth fault of the next seaward belt (Evamy et. al. (1978), Dust and Omatsola, 1990).

Doust and Omatsola (1990) described three depobelt provinces based on structures, these are:

- ✓ The Northern delta Province
- ✓ The Central delta Province
- ✓ The Distal delta Province

The Northern delta province, which overlies relatively shallow basement, has the oldest growth faults that are generally rotational, evenly spaced and increased steepness seaward.

The Central delta province has depobelt with well define structures such as successively deeper rollover crests that shift seaward for a given growth faults.

The distal delta province is the most structurally complex due to internal gravity techniques on the modern continental slope. Structurally, complexity is found to increase from north (landward) to south (seaward).

METHODOLOGY

Geophysical well logging is the recording of the properties or characteristics of the rock formations transversed by measuring apparatus in a borehole, which largely obviates the necessity of the expense of coring. The most commonly used geophysical techniques in researvoir studies are electrical resistivity, electromagnetic induction, and self-potential (SP), natural and induce radioactivity, sonic velocity and temperature. The petrophysical quantitative analysis of a study well is as follows

PETROPHYSICAL QUANTITATIVE ANALYSIS OF OPA WELL
CALCULATION OF POROSITY (∅)

Reservoir A
USING FORMULA:

$$\phi_{\text{Den}} = \left(\frac{p_{ma-}p_{b\log}}{p_{ma-}p_{f}}\right) - V_{sh} \times \left(\frac{p_{ma} - p_{sh}}{p_{ma-}p_{f}}\right)$$

Where $\phi_{\text{Den}} \Rightarrow$ porosity derived from density log

V_{sn} = Volume of shale = 0.14

ρ_{ma} = Density of matrix = 2.65g/cm^3

ρ_{sh} = Shale’s density =2.3g/cm3

ρ_{blog} = Bulk density value on density log = 2.14g/cm^3

ρ_f = Density of the fluid=1.0g/cm^3

By substitution,

$$\phi = \left(\frac{2.65 - 2.14}{2.65 - 1.0}\right) - 0.14 \times \left(\frac{2.65 - 2.3}{2.65 - 1.0}\right)$$

$$\phi = \frac{0.51}{1.65} - 0.14 \times \left(\frac{0.35}{1.65}\right)$$

$$\phi = 0.31 - 0.14 \times 0.21$$

$$\phi = 0.31 - 0.029$$

$$\phi = 0.28 \text{ or } 28\%.$$

RESERVOIR B

Where ρ_{ma} = Density of matrix = 2.65g/cm^3

$\rho_{blog\,=}$ Bulk density value on density log = 2.14

ρ_f = Density of the fluid = 1.0g/cm^3

V_{sn} = Volume of shale = 0.14

ρ_{sn} = Density of shale = 2.3g/cm^3

By substitution,

$$\phi = \left(\frac{2.65\ -2.14}{2.65-1.0}\right) - 0.37 \times \left(\frac{2.65-2.4}{2.65-1.0}\right)$$

$$\phi = \frac{0.51}{1.65} - 0.37 \times \left(\frac{0.25}{1.65}\right)$$

$$\phi = 0.31 - 0.37 \times 0.15$$

$$\phi = 0.31 - 0.059$$

$$\phi = 0.25 \text{ or } 25\%.$$

CALCULATION OF FORMATION FACTOR:

Using Humble's formula for unconsolidated formations typical Niger Delta sandstones,

$$F = \frac{0.62}{\phi^{2.15}}$$

Where F = formation factor and ϕ = porosity

Reservoir A

Where ϕ = 28%

$$F = \frac{0.62}{28^{2.15}} = \frac{0.62}{1292.4} = 0.00048$$

Reservoir B

Where ϕ = 25%

$$F = \frac{0.62}{25^{2.15}} = \frac{0.62}{1013} = 0.000612$$

CALCULATION OF IRREDUCIBLE WATER SATURATION

Irreducible water saturation (Swirr) is determined by using the below in formula:

$$\textbf{Swirr} = \left[\frac{F}{2000}\right]^{1/2}$$

Reservoir A

Where F = 0.00048

Swirr at A = $\left[\frac{0.000480}{2000}\right]^{1/2}$

$= (0.00000024)^{1/2}$ = 0.00049

Reservoir B

Where F = 0.000612

Swirr at B = $\left[\frac{0.000612}{2000}\right]^{1/2}$

$= (0.000000306)^{1/2}$ = 0.000553

CALCULATION OF PERMEABILITY

Permeability can be determined using the formula in below:

$$K = \frac{0.136 \times \phi^{4.4}}{Swirr^2}$$

Where K= Permeability

Reservoir A

Where ϕ = 0.28 and Swirr = 0.00049

By substitution,

$$K = \frac{0.136 \times 0.28^{4.4}}{(0.00049)^2} = 20924md$$

Reservoir B

Where ϕ =0.25 and Swirr = 0.000553

By substitution,

$$K = \frac{0.136 \times 0.25^{4.4}}{(0.000553)^2} = 2997.8md$$

CALCULATION OF TRANSMISSIVITY

Transmissivity can be calculated as the product of permeability and thickness.

Transmissivity = permeability × thickness

Reservoir A

Where Permeability (k) = 2092.4md and Reservoir's thickness =204ft

By substitution,

Transmissivity = 2092.4 $\times$204 = 426850mdft

Reservoir B

Where Permeability (K) = 997.8md and Reservoir's thickness =88ft

By substitution,

Transmissivity (T) = 997.8 $\times$88 = 87806mdft

CALCULATION OF WATER SATURATION (S_W)

Water saturation (S_w) = $\left(\frac{Ro}{Rt}\right)^{1/2}$

Ro =Resistivity of water bearing rock

Rt =True resistivity of the rock.

Reservoir A

Where Ro = 0.115 ohm-metres and Rt = 5.774 ohm-metres

By substitution,

$$S_w = \left(\frac{0.115}{5.774}\right)^{1/2} = 0.14$$

Reservoir B

Where Ro = 0.061 ohm-metres and Rt = 2.938 ohm-metres

By substitution,

$$S_w = \left(\frac{0.061}{2.938}\right)^{1/2} = 0.14$$

CALCULATION OF HYDROCARBON SATURATION (S_H)

$S_H + S_w =1$

$S_H =1- S_w$

Reservoir A

Where S_w =0.14

S_H =1-0.14 = 0.86

Reservoir B

Where S_w =0.14

S_H =1-0.14 = 0.86

CALCULATION OF BULK VOLUME WATER (BVW)

Bulk Volume Water (BVW) = Porosity ((∅) × saturation water (S_w)

Reservoir A

Where ∅ =0.28

S_w = 0.14

Bulk volume water (BVW) = 0.28 × 0.14 =0.039

Reservoir B

Where ∅ = 0.25

S_w = 0.14

Bulk volume water (BVW) =0.25 ×0.14 =0.035

RESULTS AND INTERPRETATION

PETROPHYSICAL CHARACTERISTICS OF RESERVOIRS OF OPA WELL

There are two hydrocarbon reservoirs found in the well. These are reservoirs A and B.

In reservoir A, it occurs at interval of 5727 – 5931ft (1746-1808m) and has a gross (G) and net (N) thickness of sand, 204ft (62.2m) and 176.5ft (53.8m) respectively, with N/G ratio of 0.87; water saturation (S_w) of 14% and hydrocarbon saturation (S_h) of 86%, porosity (ø) and permeability (K) of 28% and 2092md respectively. Its transmissivity is 426850mdft (Table 4). Therefore, the reservoir A has very good porosity and excellent permeability.

PETROPHYSICAL QUANTITATIVE ANALYSIS OF OPA WELL

Reservoirs	Depth		Gross Thickness of Sands (ft)	Net Thickness of Sands (ft)	N/G Ratio	ϕ (%)	Swirr	SW (%)	SH (%)	BVW	K(md)
	Top	Bottom									
A	5727	5931	204	176.5	0.865	28	0.00049	14	86	0.039	2092
B	7673	7761	88	70.5	0.801	25	0.00055	14	86	0.035	997.8

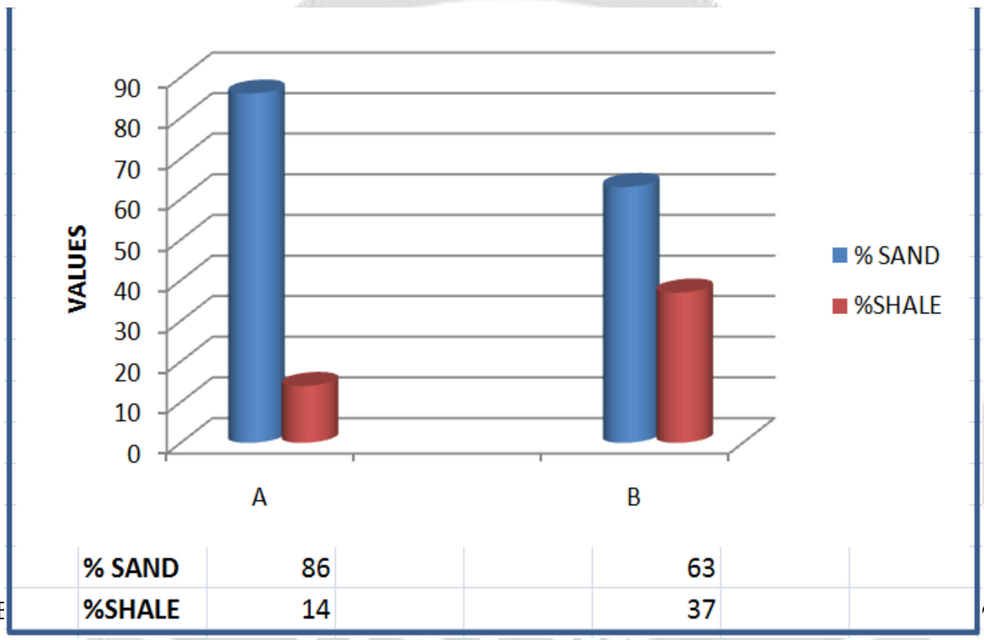
TABLE 1: SUMMARY OF PETROPHYSICAL VALUES FOR OPA WELL

The reservoir B is found at the interval of 7673 – 7761ft (2339-2366m) and has a gross (G) and net (N) thickness of sand, 88ft (26.8m) and 70.5ft (21.5m) respectively, with N/G ratio of 0.80; water saturation (S_w) of 14% and hydrocarbon saturation (S_h) of 86%, porosity (ø) and permeability (K) of 25% and 997.8md respectively. Its transmissivity is 87806mdft. (Table 1).Therefore, reservoir B has very good porosity and very good permeability.

The formation bulk volume water values calculated are nearly constant (Table 1) and this shows that the reservoir is homogeneous and is at irreducible water saturation (S_{wirr}) and therefore can produce water – free hydrocarbon. The transmissivity in reservoir A is higher than of B. This means that lateral migration of hydrocarbon from reservoir to a well bore will be easier in A than B.

GRAPHS

The graphs of sand/shale relationships were plotted to illustrate the variation of sand and shale within studied field. Table 6 shows the percentage of sand / shale calculations while figure shows their graphs.



TA[illegible] WELL.

RESERVOIRS	% SAND	% SHALE
A	86	14
B	63	37

EMPIRICAL RELATIONSHIP BETWEEN DEPTH, POROSITY AND PERMEABILITY

From the petrophysical values, both the porosity and permeability decreases down the depth (Table 2). Therefore, empirical formulas can be generated to show the relationship between (1) depth and porosity, (2) depth and permeability. These formulae can be derived from below:

Since the porosity varies inversely with depth (D) the relationship between porosity (∅) and depth can be written as

$$D \propto \frac{1}{\phi}$$

Let m represents the constant between depth and porosity

Then, $D = \frac{m}{\phi}$ -- (1)

From the graph below, variables of depth (D) and porosity were taken and empirical formula between depth and porosity can be derived in below:

$D_2 - D_1 = \frac{m}{\phi_2 - \phi_1}$ -- (2)

Where:
D_2 = 8432ft
D_1 = 5800ft
$\emptyset_1$ = 17% or 0.17
$\emptyset_2$ = 28% or 0.28

By substitution,

$$8432 - 5800 = \frac{m}{0.28 - 0.17}$$

$$2632 = \frac{m}{0.11}$$

m = (2632ft) x (0.11) --- (3)

The empirical formula between depth (d) and porosity can be written as:

$D = 289.52\emptyset^{-1}$ -- (4)

Therefore, $\emptyset = 289.52\, D^{-1}$ --- (5)

Where:
D= depth (feet)
$\emptyset$ = porosity.

Depth is in feet can be converted into metres as follow:

2632 x 0.3048 = 802.2 metres (1 foot = 0.3048m) ----------------(6)

From the above equation, m = (2632 x 0.3048) x (0.11)
m = 802.2 x0.11
m = 88.25

The empirical formula between depth and porosity can be written as:

$D = 88.25\emptyset^{-1}$ --(7)

Therefore, $\emptyset = 88.25\, D^{-1}$--(8)

Where:
D = depth (metres).
$\emptyset$ = porosity

Similarly, the empirical formulas between depth (ft) and permeability (k) can be derived in below:
Permeability (k) decreases as the depth increases.

$$D \propto \frac{1}{K}$$

Let N represent the constant relationship between depth permeability

$D = \frac{N}{K}$ -- (9)

$$D_2 - D_1 = \frac{N}{k2 - k1}$$ -- (10)

Where: D_2 = 7717ft & D_1 = 5757.5ft
K_2 = 2895md & k_1 = 997.8md
By substitution,

$$7717 - 5757.5 = \frac{N}{2895 - 997.8}$$

$$\frac{1959.5}{1} = \frac{N}{1897.2}$$

N = 1959.5 x 1897.2 --- (11)
N = 3717563.4 -- (12)

GRAPHICAL DETERMINATION OF IRREDUCIBLE WATER SATURATION

CONSTANT (SWIRR) LEADING TO EMPIRICAL FORMULA BETWEEN POROSITY AND PERMEABILITY

From the Dresser Atlas equation of Permeability,

$$K = \frac{0.136 \times \phi^{4.4}}{(swirr)^2}$$

$$(swirr)^2 = \frac{0.36 \times \phi^{4.4}}{k}$$ ……………………………… (13)

$$S = \frac{B_2 - B_1}{K_2 - K_1}$$ …………………………………(14)

Where:

$B_2 = 58.6 \times 10^{-5}$

= 0.000586

$B_1 = 17.4 \times 10^{-5}$

= 0.000174

K_2 = 2895

K_1 = 424.6

TABLE 3: SHOWING RELATIONSHIP BETWEEN POROSITY AND PERMEABILITY

Ø(%)	$Ø^{4.4}$	**B = (0.136xØ$^{4.4}$)**	**K (md)**
0.32	6.65 x 10^{-3}	0.000904	5024
0.29	4.31 x 10^{-3}	0.000586	2895
0.28	3.69 x 10^{-3}	0.000502	2092
0.25	2.24 x 10^{-3}	0.000305	997.8
0.22	1.28 x 10^{-3}	0.000174	424.6
0.19	6.71 x10^{-4}	0.0000912	166.5
0.18	5.29 x 10^{-4}	0.0000719	116.2
0.17	4.11 x 10^{-4}	0.0000559	79.9
0.14	1.75x 10^{-4}	0.0000238	22.4

The reservoirs for the discovered hydrocarbons in the study area are sandstones within the Agbada Formation. Petrophysical evaluation was carried out on the geophysical wireline logs. A total of two hydrocarbon reservoirs were identified and evaluated. The petrophysical parameters of reservoir A range from 32-22%, 5024-116.2md, 20-14% and 86 – 80% for porosity (ø), permeability (K), water saturation (S_w) and hydrocarbon saturation (S_h), respectively. From the Dresser standard, the porosity (ø) ranges from excellent to very good, while the permeability (K) is excellent. Its transmissivity ranges from 50952mdft–648148 mdft.

The petrophysical parameters of the reservoir B range from 30-18%, 1997.8 -166.5md, 30-14% and 86 – 70% for porosity (ø), permeability (K), water saturation (S_w) and hydrocarbon saturation (S_h), respectively. Its transmissivity ranges from 14935 – 87806mdft. From the Dresser standard, the porosity (ø) ranges from very good to good, while its permeability (K) ranges from excellent to good.

The reservoirs bulk volume water (BVW) values calculated are close to constant, this indicates that the reservoir are homogenous and at irreducible water saturation. Therefore, reservoirs can produce water – free hydrocarbon. When a reservoir is at irreducible water saturation, water saturation (S_w) will not move because it is held on grains by capillary pressure. The petrophysical parameters show a gradual decrease from the top to bottom of the wells, reflecting increase in compaction with depth. The porosity, permeability and transmissivity also followed the same trend.

REFERENCES

Adedokun, O. (1981). Petrology, provenance and depositional environments of the reservoir sandstone of Ossu-Izombe oil field, Imo State, Nigeria. *Journal of Geology*, 4:35-36.

Adeleye, D. (1975). Nigeria Late Cretaceous stratigraphy and paleogeography. American Association of Petroleum Geologist, bulletin p. 2302-2312.

Adegoke, O.; Agumanu, R.; Benkhelil, J. and P. Ajayi (1978). New Stratigraphic, Redimentologic and structural data on the kerri-kerri, formation, Banchi and Borno states, Nigeria. *Journal of African Earth Sciences*, 5:249-277.

Adeleye, D. and T. Dessauvogie (1970). Stratigraphy of the Niger embayment near Bida, Nigeria African Geol. Ibadan, p. 181-186.

Allix, P. (1983). Environments mesozoiques de la partie nordorientale du fosse de la Benoue, (Nigeria). Stratigraphie–sedimentologies. Evolution geodynamique. Trav. Lab. Sci. Terr., St. Jerome, Marseille France B21, p. 1-200.

Allen, J. (1963). Sedimentation in the modern Delta of the River Niger, West Africa. Proc. 6 th Internal Conf. Sedimentologist. p. 26-34

Allen, J. (1964). The Nigerian Continental Margin: Bottom Sediments, submarine morphology and geological evolution Marine Geology, 1:289-332.

Allen, J. (1965). Late Quaternary Niger Delta and adjacent areas sedimentary environments and Lithofacies: American Association of Petroleum Geologist , En Mijinb, 44: 1-21.

Allen, J. (1980). Sedimentary structures, their character and physical basis Development Sedimentol. 3007 and B, Vol. 1, York: Elsevier Sci. Publ. Company.

Amajor, L. and D. Agbaire (1984). Depositional history of the reservoir sandstones, Akpor and Apara oilfield, Eastern Niger Delta, Nigeria: Journal of Petroleum Geology.

Etu-Efeofor, J. (1997). Fundamentals of Petroleum Geology, Paragraphics (An imprint of Jeson Services) Publisher, Port Harcourt. p. 1-146.

Oloto, I. (1992). Succession of Polynomorphs from the Early Eocene of Gbekebo – 1 Well in S.W. Nigeria. Journal of African Earth Sciences, vol. 15, No. 34, p. 444.

Wright, J. (1970). The Benue Valley – a rip in the African Continent: Nigeria field Vol. xxxv. No. 2, p. 78-85.