PETROPHYSICAL ANALYSIS AND RESERVOIR POTENTIAL OF UKU-1 WELL, X-FIELD, NIGER DELTA. NIGERIA

ADIELA, U.P [1] AYODELE MOSES [2]. AZUBUIKE-IJOMAH KELECHI [3]

[3] Department of Petroleum Engineering,, Nigerian Agip Oil Company, Port Harcourt

[2,3] Department of Geology, University of Port Harcourt, Port Harcourt, Nigeria

ABSTRACT

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.

(I) INTRODUCTION

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

Reserve estimation therefore, is based on the field wide distribution of these reservoir properties. Due to the intense petroleum exploration and exploitation activities in the Niger Delta region during the last two decades, vast amount of data have been accumulated from which it had been possible to establish the historical reconstruction and evolution of the Niger Delta basin This research work is on 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.

LOCATION OF STUDY

The field under study is pseudo-named “X’’ field in accordance with the Oil company confidentiality agreement. 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.

(II) METHODOLOGY

PETROPHYSICAL QUANTITATIVE ANALYSIS OF UKU-1 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 = 0.40

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

ρ_{sh} = Shale's density = 2.35 g/cm^3

ρ_{blog} = Bulk density value on density log = 2.17 g/cm^3

ρ_f = Density of the fluid= 1.0g/cm^3

By substitution,

$$\phi = \left(\frac{2.65 - 2.17}{2.65 - 1.0}\right) - 0.40 \times \left(\frac{2.65 - 2.35}{2.65 - 1.0}\right)$$

$$\phi = \frac{0.48}{1.65} - 0.40 \times \left(\frac{0.3}{1.65}\right)$$

ϕ = 0.29 – 0.40 × (0.182)

ϕ = 0.29 – 0.073

ϕ = 0.22 or 22%

Reservoir C

Where ρ_{ma} =2.65g/cm^3

$\rho_{\text{blog}=}$ 2. 28g/cm^3

ρ_f = 1.0g/cm^3

$V_{sn=}$ 0.25

ρ_{sn} = 2.33

By Substitution,

We have $\phi = \left(\frac{2.65 - 2.28}{2.65 - 1.0}\right) - 0.25 \times \left(\frac{2.65 - 2.33}{2.65 - 1.0}\right)$

$$\phi = \left(\frac{0.37}{1.65}\right) - 0.25 \times \left(\frac{0.32}{1.65}\right)$$

ϕ = 0.22 – (0.25 × 0.19)

ϕ = 0.22 – 0.05

ϕ = 0.17 or 17%

CALCULATION OF FORMATION FACTOR

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

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

Where F= formation factor

ϕ= Porosity

Reservoir A

Where ϕ = 22%

$$F = \frac{0.62}{22^{2.15}} = \frac{0.62}{769.5} = 0.000806$$

Reservoir C

Where ϕ = 17%

$$F = \frac{0.62}{17^{2.15}} = \frac{0.62}{442.0} = 0.0014$$

CALCULATION OF HYDROCARBON SATURATION (S_H)

$S_H + S_w = 1$

$S_H = 1 - S_w$

Reservoir A

Where S_w =0.18

S_H =1-0.18 = 0.82

Hydrocarbon saturation (S_H) at Reservoir A = 0.82

Reservoir C

Where S_w =0.19

S_H =1-0.19 = 0.81

Hydrocarbon saturation (S_H) at Reservoir C = 0.81

(III) RESULTS AND INTERPRETATION

PETROPHYSICAL RESULTS AND INTERPRETATION

Total of two hydrocarbon reservoirs were identified and evaluated. The following petrophysical parameters were quantitatively analyzed for the reservoirs: Volume of Shale (V_{sh}), Porosity (ø), formation factor (F), Irreducible water saturation (S_{wirr}), permeability (K), water saturation (S_w), Hydrocarbon saturation (S_h) and Bulk volume water (BVW). The results are summarized in Table 2 and

TABLE 1: SUMMARY OF PETROPHYSICAL VALUES FOR UKU-1 WELL

Reservoirs	Depth		Thickness (ft)	N/G Ratio	ϕ (%)	Swirr	S_W (%)	S_H%	BVW	K (MD)	T(mdft
	Top	Bottom									
A	5706	5831	125	0.804	22	0.0006	18	82	0.040	432	54000
C	8376	8488	112	0.804	17	0.0008	19	81	0.032	79.9	8949

CHARACTERISTICS OF RESERVOIRS OF UKU-1 WELL

Both reservoirs A and C have hydrocarbon. In reservoir A, it is found at the interval of 5706 – 5831ft (1739-1777m) and has a gross (G) and net (N) thickness of sand, 125ft (38.1m) and 100.5ft (30.6m) respectively, with N/G ratio of 0.80; water saturation (S_w) of 18% and hydrocarbon saturation (S_h) of 82%, porosity ((ø) and permeability (K) of 22% and 432md respectively while its transmissivity is 54000mdft. Therefore, the reservoir has good porosity and very good permeability.

In reservoir C, the hydrocarbon occurs at interval of 8376 – 8488ft (2553-2587m) and has a gross (G) and net (N) thickness of sand, 112ft (34.1m) and 90ft (27.4m) respectively, with N/G ratio of 0.19; water saturation (S_w) of 19% and hydrocarbon saturation (S_h) of 81%, porosity (ø), permeability (K) and transmissivity are 17%, 79.9md and 8949mdft respectively (Table 4). The reservoir C therefore, has both good porosity and permeability.

The formation bulk volume water values calculated are nearly constant (Table 2) 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 C. This means that lateral migration of hydrocarbon from reservoir to a well bore will be faster in A than C.

GRAPHS

The graphs of sand/shale relationships were plotted to illustrate the variation of sand and shale within studied field. Table 3 shows the percentage of sand / shale calculations.

TABLE 2: RESERVOIR SAND/SHALE PERCENTAGE CALCULATIONS FOR UKU-1WELL

UKU-1 WELL		
RESERVOIRS	**% SAND**	**% SHALE**
A	60	40
C	75	25

GENERATING EMPIRICAL RELATIONSHIP BETWEEN DEPTH, POROSITY AND PERMEABILITY

From the petrophysical values, both the porosity and permeability decreases down the depth . 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

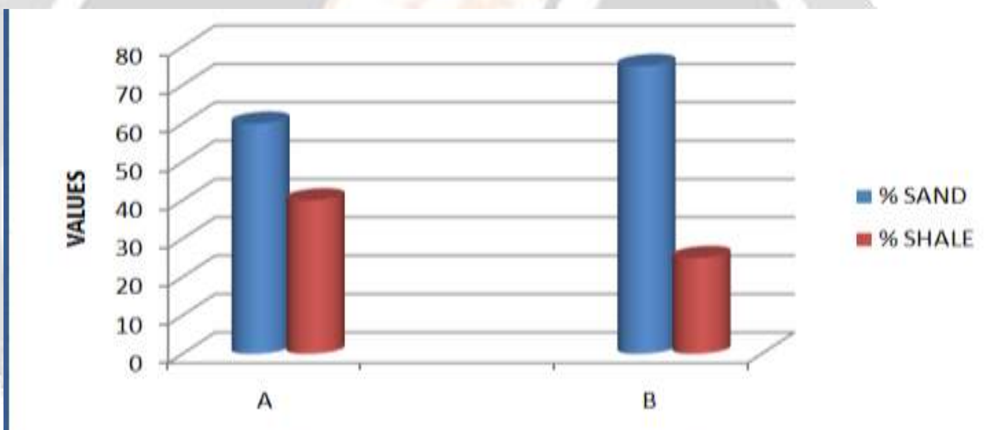
$$D \propto \frac{1}{\phi} \quad \text{--------------------------------(1)}$$

Let m represents the constant between depth and porosity.

$$\text{Then, } D = \frac{m}{\phi} \quad \text{--(2)}$$

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

Reservoir Sand/Shale % for Uku -1Well



	A		B	
% SAND	60		75	
% SHALE	40		25	

Figure 1: Graph showing the relationship between reservoir sand and shale

$$D_2 - D_1 = \frac{m}{\phi_2 - \phi_1} \quad \text{--(3)}$$

Where:
D_2 = 8432ft
D_1 = 5800ft
ϕ_1 = 17% or 0.17
ϕ_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) -- (4)

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

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

Therefore, $\emptyset = 289.52\ D^{-1}$ --(6)

Where:

D= depth (feet)

∅ = porosity.

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

2632 x 0.3048 = 802.2 metres (1 foot = 0.3048m) ----------------(7)

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:

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

Therefore, $\emptyset = 88.25\ D^{-1}$--(9)

Where:

D = depth (metres).

∅ = 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

$$D = \frac{N}{K} \quad \text{---(10)}$$

$$D_2\text{-}D_1 = \frac{N}{k2 - k1} \quad \text{---(11)}$$

Where: D_2 = 7717ft & D_1 = 5757.5ft

K_2 = 2895md & k_1 = 997.8md

By substitution,

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

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

N = 1959.5 x 1897.2 --- (12)

N = 3717563.4 --- (13)

The empirical formula between depth (ft) and permeability is given as:

$D = 3717563.4K^{-1}$, that is approximately as

$D = 3.7 \times 10^6 K^{-1}$ --(14)

Therefore, $K = 3.7 \times 10^6 D^{-1}$ --(15)

Where D= depth (feet) and K = Permeability (md)

Another formula can be derived when feet is converted into metres and can be derived as below:

From equation (25),

N = 1959.54 x 1897. 2

But 1959ft = (1959.5 x 0.3048) metres = 597.3m

Hence, N = 597.3 x 1897.2 = 1133113.3

The empirical formula between depth (m) and permeability (k) can be given as:

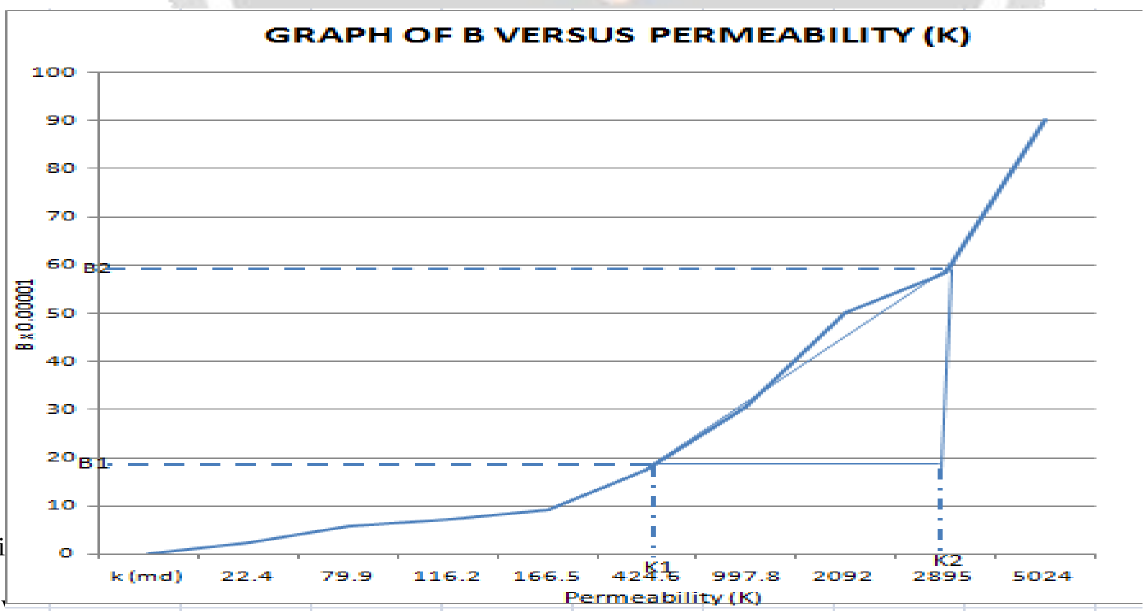
$D = 1133113.3\ K^{-1}$, that is approximately as:

$D = 1.1\text{x}10^{6}\ K^{-1}$ ---(16)

Therefore, $K = 1.1\text{x}10^{6}\ D^{-1}$---(17)

TABLE 4: SHOWING RELATIONSHIP BETWEEN POROSITY AND PERMEABILITY

Ø(%)	$Ø^{4.4}$	**B = (0.136xØ$^{4.4}$)**	**K (md)**
0.32	6.65×10^{-3}	0.000904	5024
0.29	4.31×10^{-3}	0.000586	2895
0.28	3.69×10^{-3}	0.000502	2092
0.25	2.24×10^{-3}	0.000305	997.8
0.22	1.28×10^{-3}	0.000174	424.6



Fi

By substitution,

$$\frac{0.000586 - 0.000174}{2895 - 4246}$$

Slope of the graph $= \dfrac{0.00412}{2470.4}$

$$= 1.668 x 10^{-7}$$

Where: $(swirr)^2 = \dfrac{B}{K}$

$$(swirr)^2 = \frac{B_2 - B_1}{K_2 - K_2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(18)$$

$$swirr = \sqrt{\frac{B_2 - B_1}{K_2 - K_2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(19)$$

Equating equation (36) and (38), Therefore,

$$swirr = \sqrt{\text{slope of the graph}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(20)$$

Where, slope of the graph = $1.668 \text{ x } 10^{-7}$ (Fig.25)

$$swirr = \sqrt{1.668 \text{ x } 10^{-7}}$$

Swirr = $4.084 \text{ x } 10^{-4}$

= 0.00041

Therefore, graphical determination of irreducible water saturation constant in the study area is 0.00041.

Hence, Dresser Atlas equation of permeability can be written; this can be shown in below:

Recall, dresser atlas equation of permeability:

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

From the graph, irreducible water saturation constant has been derived, this is 0.00041

Where, swirr = 0.00041

By substitution,

$$K = \frac{0.136 \times \phi^{4.4}}{(0.00041)^2}$$

$$K = \frac{0.136x\phi^{4.4}}{1.681x10^{-7}}$$

K = 809, 042.2x $\phi^{4.4}$ ……………………………………………………..(21)

The equation (40) can be approximately as:

K = 8.09 x 10^5 x $\phi^{4.4}$ ....(22)

Therefore, empirical formula between Permeability and Porosity is generated

as:

K = 8.09 x 10^5 x $\phi^{4.4}$ ……………………………………….............(23)

In reservoir A, both porosity and permeability are excellent while its transmissivity is the highest. The hydrocarbon saturation ranges 86 – 80%. .

Reservoir C has fair porosity and moderate permeability. The hydrocarbon saturation ranges 81-80%. Its transmissivity is the least.

With these petrophysical values, the reservoirs of the study area can be said to be prolific in terms of hydrocarbon production and they will produce water-free hydrocarbon due to the fact that all these reservoirs are homogenous and at irreducible water saturation.

The quality of the reservoirs in terms of porosity, permeability and transmissivity decreases down the depth. Therefore, it can be concluded that the hydrocarbon potential and productivity of the reservoir sands can be classified in decreasing order of arrangement as A and C. The reservoir A in 019 is the best in terms of hydrocarbon production and hydrocarbon in such wells can easily migrate to the wellbore as compared to other two reservoirs.

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.

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.

Amajor, L. and F . Lebekmo (1990). The Vicking (Albian) Reservoir Sandstones of central and south-centra Alberta, Canada. Part 1 Geometry and Depositional History: Journal of Petroleum Geology 13 (3), p. 315 – 328.

Akaegbobi, I. and O. Tegbe (2000): Reservoir heterogeneities as a controlling factor to the abnormal production performance of the oil field "y", NE, Niger Delta, NAPE bull., 15: 81-91.

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