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Petroleum Prospectively Evaluation of Wells 001 And 002, Agbada Formation, Niger Delta, Nigeria

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ABSTRACT

This study reveals that the reservoirs of the study area is prolific in terms of hydrocarbon production and they will produce water-free hydrocarbon due to the fact that all the reservoirs are homogenous and at irreducible water saturation. The quality of the hydrocarbon reservoirs (A, B, C) in terms of porosity, permeability and transmissivity decreases down the depth, therefore, it can be concluded that hydrocarbon potential and productivity of the reservoirs sand can be classified in decreasing order of arrangement as A, B and C. Hence, the reservoir A in well 001,and 002 is the best in terms of hydrocarbon production.

INTRODUCTION.

The Niger Delta is a prograding depositional complex within the Cenozoic formation of Southern Nigeria. It is situated between longitudes 3^0 and 9^0 E and latitudes 4^0 and 6^0 N. It is a prolific oil province where one petroleum system, the Tertiary Niger Delta (Akata-Agbada) petroleum system has been identified and is one of the largest in the West African sub-region

Reservoirs in the Niger-Delta exhibit a wide range of complexities in their sedimentological and petrophysical characteristics due to the differences in hydrodynamic conditions prevalent in their depositional settings. 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.

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 STUDIED WELLS

The study wells are located offshore, off the Nigerian coast, at a distance of 120km southwest of the Niger Delta. . The field covers approximately 60 km^2 in an average water depth of 1,000 metres (3,300 ft). but the co-ordinates of the location of this field were concealed due to proprietary reasons.The field produces both **petroleum** and **natural gas** (**See figure 1 below).**

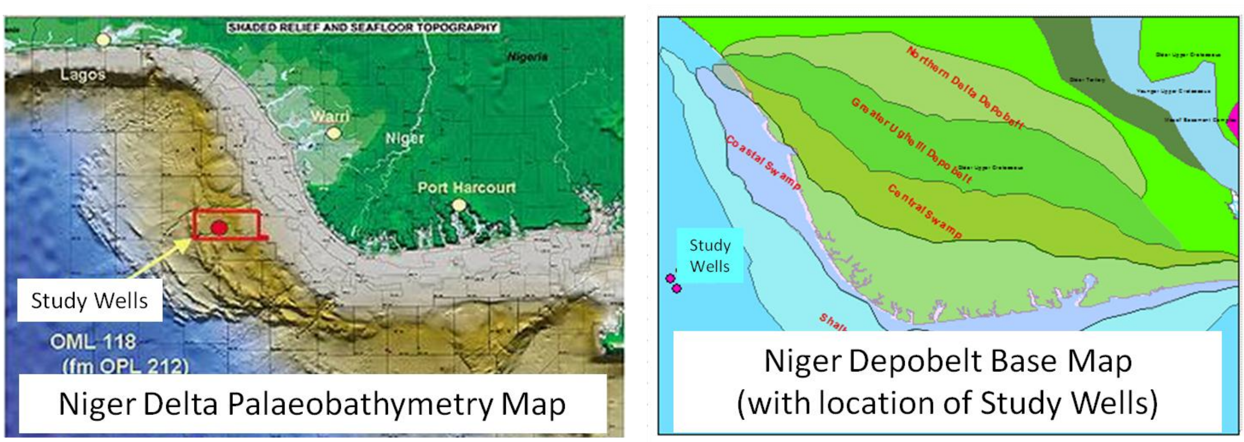

Figure 1.Niger Delta Paleobathymetry and Depobelt base map (showing location of study wells)

OBJECTIVES OF STUDY

This research is aimed at evaluating the reservoir potential of H-field with limitation to the available data primarily to determine the petrophysical characteristics of sand bodies.

(III) 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. Casing may be introduced into the borehole section immediately after drilling to prevent the collapse of the wall rocks in the borehole section lined pipe. Generally, any of the normal geophysical techniques can be adapted in borehole logging. The most commonly used is the techniques are electrical resistivity, electromagnetic induction, and self-potential (SP), natural and induce radioactivity, sonic velocity and temperature.

The instrumentation necessary for borehole logging is housed in a cylindrical metal tube known as *sonde*. Sondes are suspended in the borehole from an armoured multi-core cable. During logging, the sonde is gradually pulled up from the borehole bottom at a certain speed. The petrophysical characteristics of Reservoir sands in Well-001 are calculated and analyzed below

PETROPHYSICAL QUANTITATIVE ANALYSIS OF WELL 001
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,

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

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

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

$$\phi = 0.31 - 0.029$$

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

RESERVOIR B

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

ρ_{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 $\phi = 28\%$

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

Reservoir B

Where $\phi = 25\%$

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

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

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

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

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 ×204 = 426850mdft

Reservoir B

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

By substitution,

Transmissivity (T) = 997.8 ×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 (($\emptyset$) × saturation water (S_w)

Reservoir A

Where $\emptyset = 0.28$

$S_w = 0.14$

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

Reservoir B

Where $\emptyset = 0.25$

$S_w = 0.14$

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

(IV) RESULTS AND INTERPRETATION

PETROPHYSICAL RESULTS AND INTERPRETATION

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 1 and 2.

Petrophysical evaluation was carried out for the reservoir sand bodies from wireline logs by using relations (formulae) that are universally used in the estimation of reservoir sands bodies of the following petrophysical parameters: Volume of Shale (V_{Sh}), Porosity (ϕ), Formation Factor (F), Irreducible Water Saturation (Swirr), Permeability (K), Water Saturation ($S_{w)}$, Hydrocarbon Saturation (S_h) and Bulk Volume Water (BVW).

CHARACTERISTICS OF RESERVOIRS OF WELL 001 There are two hydrocarbon reservoirs found in the well 001 These are reservoirs A and B.

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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.

TABLE 1: PETROPHYSICAL QUANTITATIVE ANALYSIS of WELL 001

Reservoirs	Thickness (ft)	Net Thickness of Sands (ft)	N/G Ratio	ϕ (%)	Swirr	SW (%)	SH (%)	BVW	K(md)	T(mdft)
A	204	176.5	0.865	28	0.00049	14	86	0.039	2092	426850
B	88	70.5	0.801	25	0.00055	14	86	0.035	997.8	87806

TABLE 2 PETROPHYSICAL QUANTITATIVE ANALYSIS of WELL 002

Reservoirs	Thickness (ft)	Net Thickness of Sands(ft)	N/G Ratio	ϕ (%)	Swirr	S_W (%)	S_H%	BVW	K (MD)	T(mdft)
A	125	100.5	0.804	22	0.0006	18	82	0.040	432	54000
C	112	90	0.804	17	0.0008	19	81	0.032	79.9	8949

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 4).Therefore, reservoir B has very good porosity and very good permeability.

The formation bulk volume water values calculated are nearly constant (Table 4) 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.

CHARACTERISTICS OF RESERVOIRS OF WELL 002 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 (Table 4). 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 4) 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.

Table 3: RESERVOIR SAND/SHALE PERCENTAGE CALCULATIONS FOR WELLS.

WELL 001

RESERVOIRS	% SAND	% SHALE
A	86	14
B	63	37
WELL 002		
RESERVOIRS	**% SAND**	**% SHALE**
A	60	40
C	75	25

GRAPHICAL DETERMINATION OF IRREDUCIBLE WATER SATURATION CONSTANT (SWIRR) LEADING TO EMPIRICAL FORMULA BETWEEN POROSITY AND PERMEABILITY

From the Dresser Atlas equation of Permeability,

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

$$(swirr)^2 = \frac{0.36 \times \phi^{4.4}}{k} \qquad \text{.......................................(1)}$$

$$swirr = \sqrt{\frac{0.36 \times \phi^{4.4}}{K}} \qquad \text{.......................................(2)}$$

Let B = 0.36 x $\phi^{4.4}$

Equation becomes

$$swirr = \sqrt{\frac{B}{K}} \qquad \text{..(3)}$$

$$(swirr)^2 = \frac{B}{K} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Table 7 showing variation of porosity and permeability which was used to plot the graph of B against K inorder to determine the irreducible water saturation constant.

Slope of the graph (Fig. 25) can be derived as

$$S = \frac{B_2 - B_1}{K_2 - K_1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where:

$B_2 = 58.6 \text{ x}10^{-5}$

$= 0.000586$

$B_1 = 17.4 \text{ x}10^{-5}$

$= 0.000174$

$K_2 = 2895$

$K_1 = 424.6$

TABLE 4: 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

substitution,

$$\text{Slope of the graph} = \frac{0.000586 - 0.000174}{2895 - 4246} = \frac{0.00412}{2470.4}$$

$$= 1.668x10^{-7}$$

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

$$(swirr)^2 = \frac{B_2 - B_1}{K_2 - K_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$swirr = \sqrt{\frac{B_2 - B_1}{K_2 - K_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

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

$$swirr = \sqrt{\text{slope of the graph}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(8)$$

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

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

Swirr = 4.084 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 $\phi^{4.4}$ …………………………………………………….(9)

The equation (40) can be approximately as:

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

Therefore, empirical formula between Permeability and Porosity is generated as:

K = 8.09 x 10^5 x $\phi^{4.4}$ ……………………………………….............(11)

DISCUSSION

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 three hydrocarbon reservoirs were identified and evaluated. Reservoir A cuts across the six wells 007, 002 . 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 petrophysical parameters of the reservoir C ranges from 14-17%, 79.9 – 22.4md, 20-19%, 81-80% for porosity (ø), permeability (K), water saturation (S_w) and hydrocarbon saturation (S_h) respectively. Its transmissivity ranges 8449 to 1993.6mdft. From the Dresser standard, the porosity (ø) ranges from good to fair while its permeability (K) ranges from good to moderate.

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.

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