

# Composite Estimation of Permeability in Identified Hydrocarbon Reservoirs of Langbodo Field Niger Delta, Nigeria

Damilare S Adepehin<sup>1</sup>, Oluwaseyi A Dasho<sup>2</sup>, Matthew I Amanyi<sup>1</sup>, Ayodeji B Babinisi<sup>2</sup>, Abdulazeez O Salawu<sup>3</sup>, Stephen O Adikwu<sup>1</sup>, Emmanuel D Onoja<sup>1</sup> and Inalegwu A Ngbede<sup>1</sup>

<sup>1</sup> Department of Physics, Federal University of Health Sciences, Otuokpo, Benue State, Nigeria

<sup>2</sup> Department of Physical Sciences, Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State, Nigeria

<sup>3</sup> Department of Computer Science, Nile University of Nigeria, F.C.T, Abuja, Nigeria

Corresponding E-mail: [damilare.adepehin@fuhso.edu.ng](mailto:damilare.adepehin@fuhso.edu.ng)

Received 25-02-2022

Accepted for publication 07-04-2022

Published 12-04-2022

## Abstract

This study identified the fluid types and boundaries present within selected reservoirs in Langbodo field, using petrophysical parameters based on estimated rock properties such as porosity, permeability, irreducible water saturation, hydrocarbon saturation and bulk water volume. This was with a view to correcting the salient reservoirs heterogeneities anomalies error inherent in building of an ideal realistic reservoir models. The quality of the data obtained were checked and despiked to eliminate null values. Petrel version 2009 and OpendTect 4.6.0 Exploration and production softwares were used for the quality interpretations of data, such as lithology identification, delineation of potential reservoirs and determination of fluids and fluids contacts. Estimation of quantitative petrophysical parameters were done by inputting the data into Microsoft excel 2015 version softwares and adopting appropriate mathematical relations, such as the Tixier, Timur and the Coates and Dumanoir models for the permeability (K). Realistic estimation of the permeability was done by comparing the average of the Tixier, Timur and the Coates and Dumanoir models with each of the models. The composite model obtained, mirrors the behavior of the Timur's permeability which is higher than that of the Tixier and the Coates and Dumanoir. Integration of the Archie's equation and neutron – density crossplot confirmed the presence of substantial hydrocarbon in the reservoirs, although producibility indicators revealed that the reservoirs may not be producible without enhanced oil recovery method(s). This study established that the composite model is a better representation of K in the study area because it agrees with the Timur's estimation model.

Keywords: Petrophysical parameters; Lithology; Delineation; Composite; Neutron – Density Crossplot.

## I. INTRODUCTION

The geometric progression of the world population has called for higher demand for energy, of which hydrocarbons constitute a dominant percentage, especially among the non-renewable energy sources. Multinational hydrocarbon exploration companies may experience poor reservoir performance within few years of production due to inadequate reservoir properties description [1]. The success of any hydrocarbon exploration program depends on the building of reliable reservoir models [1]. Some of the most important parameters needed to characterize reservoir quality are permeability, porosity and shale volume. Their accurate prediction is the basis upon which one can actually identify if the reservoir is producible. The description of reservoir characteristics and fluid flow performance can be anchored on the permeability and this plays a very important role in designing exploration and development plan [2]. An accurate estimation of the permeability enhances oil and gas field development and it is the basis for building geophysical models, accurately predicting oil and gas reserves and taking reasonable development plan [3]. The importance of accurate estimation of the permeability cannot be overemphasized as other petrophysical parameters are dependent directly or indirectly on it. Therefore, accurate estimation of the permeability in identified reservoirs is undoubtedly important to enhance validity of other dependent variables. Unfortunately, diverse methods, with varying strengths and weaknesses have been proposed by various researchers. The Tixier's model of 1949, the Timur's model of 1968 and the Coates and Dumanoir's model of 1981 [4-6], were applied by several researchers [7-10], with little or no cognizance to the weaknesses inherent in such approaches. These models are based on correlation between permeability and other geophysical parameters such as porosity and irreducible water saturation. The estimation of permeability from the aforementioned models is often accompanied with varying strengths and weaknesses; which the ignorant and unsuspecting explorationist may not watch out for; depending on the peculiarity of the geology of the area under consideration. Therefore, this research work is aimed at enhancing the computation of the permeability by integrating the strengths of the diverse methods for estimating the parameter, using suites of well logs from "Langbodo field" Niger Delta. This research finding will improve reservoir quality assessment, and assist other producibility indicators to rank the reservoirs for further developmental decisions.

## II. STUDY AREA

The study area is located in the "Langbodo field" onshore Niger Delta. It is located within the Shell Petroleum Development Company acreage. The field is bounded by latitudes  $4^{\circ} 46' N$  and  $5^{\circ} 57' N$  and longitudes  $5^{\circ} 37' E$  and  $5^{\circ} 64' E$ . Fig. 1 and 2 are maps showing the study area

and well location points respectively. The subsurface geology of the study area reveals the Niger Delta Basin. The wells drilled in the study area enabled the acquisition of wireline logs, utilized for this study.

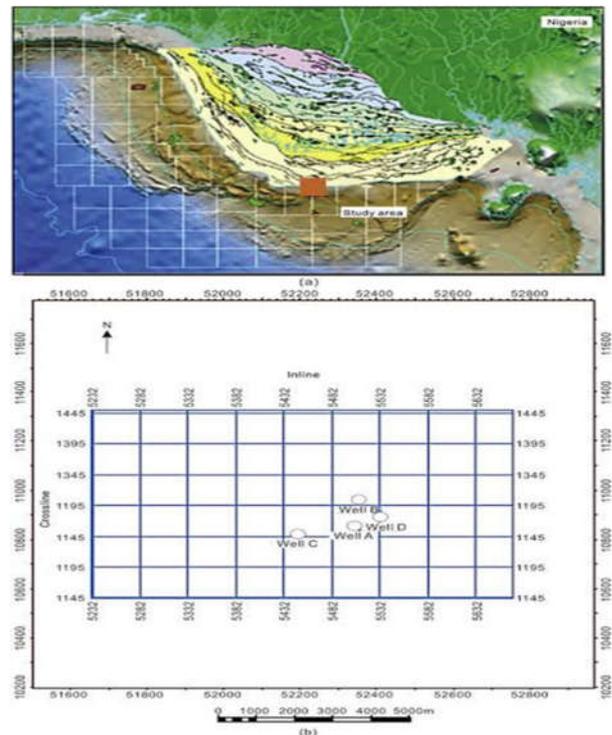


Fig. 1 An Outlay of the "Langbodo Field" showing Well Locations

The geology of the Niger Delta revealed an extensional rift basin located in the Niger Delta and the Gulf of Guinea on continental margin close to the western coast of Nigeria. It has an established access to Equatorial Guinea, Cameroon and Sao Tome and Principe. The complexity of the basin is shown in the content of high productive hydrocarbon system. The Niger Delta basin is one the largest sub-aerial basins in Africa which is composed of several geologic formations that indicate how the basin could have initially formed and the large scale tectonic of the area. Research shows that some other basins formed from similar geologic processes exist around the Niger Delta. Its formation can be traced to a failed rift junction formed during the separation of the South American plate and the African plate, as the South Atlantic started to open [10]. The origin of rifting in this basin started in the late Jurassic and terminated in the mid Cretaceous. Continuation of rifting led to the formation of several faults many of which are thrust faults. Also at this time, the late Cretaceous harbors some deposition majorly composed of syn-rift sand and shale. This shows that the shoreline regressed during this time. Concurrently, the basin had been witnessing extension leading to high angle normal faults and fault block rotation. At the origin of the Paleocene, there was a noticeable shoreline

transgression. During the Paleocene, the Akata Formation was deposited. At the time of the Eocene, the Agbada Formation followed the underlying Akata shale [12]. This formation loading caused the underlying shale Akata Formation to be

compressed and squeezed into shale diapirs. The Oligocene, the Benin Formation was thereafter deposited. It is the shallowest part of the sequence with age of formation varying from earlier to recent [12].



Fig. 2 Location Map of the Petroliferous Niger Delta, Showing the Important Frame and Tertiary Delta Growth [11].

### III. MATERIALS AND METHODS

If Suites of wireline logs that include the gamma ray, density, neutron, sonic, resistivity and caliper logs from three exploration wells were utilized for this study. These data were checked and despiked to eliminate null values. Data were

thereafter loaded into petrel version 2009 and OpendTect 4.6.0® exploration and production software to enable qualitative interpretations such as lithology identification, delineation of potential reservoirs, determination of reservoir fluids and fluid contacts. Estimation of quantitative petrophysical parameters was done by inputting the data into

Microsoft excel® software and adopting appropriate mathematical/ statistical valuations to evaluate the delineated reservoirs.

Enhanced computation of the permeability (K) of reservoirs involve a detailed qualitative and quantitative evaluation of other petrophysical parameters such as the lithology, porosity, water and hydrocarbon saturation among others. The analytic procedure is aimed at a better estimation of permeability (K). This will as well assist in determining quality of the reservoirs. Results obtained from at least three methods of estimating the reservoir permeability were used to arrive at a better K of the reservoirs. A systemic analysis suitable for this case was adopted for the estimation of the permeability of reservoirs of interest penetrated by the “Langbodo” wells. The Schlumberger Petrel Software was used to enhance interpretation. Microsoft excel was used to estimate K from various equations; as well as comparing obtained results. Table I below summarizes the data set used for this research. The Wells A, B and C penetrated a total of 11500 ft, 11620 ft and 12,035 ft respectively.

Table I Available logs from the three wells used for the research

Wells	Gamma ray	Density	Neutron Resistivity	Spontaneous potential	Sonic	RT	Caliper
A	A	A	A	A	A	N	A
B	A	A	A	A	N	A	A
C	A	A	A	A	A	N	A

Legend	
A	Available
N	Not Available

#### IV. DETERMINATION OF RESERVOIRS PERMEABILITY

Permeability is the rock property to transmit fluids. It is determined by the size of the connecting passages (pores throats or capillaries) between pores. Permeability is a key parameter associated with the characterization of any hydrocarbon reservoir. It is measured in Darcies or millidarcies. The Tixier (1949), Timur (1968) and the Coates and Dumanoir (1981) equations were used to derive the permeability of each reservoir that was identified on the Langbodo field.

##### A. Permeability Estimation by Tixier Method

Tixier, 1949 proposed that permeability (K) is a direct function of reservoir cubic porosity and an indirect function of the reservoir irreducible water saturation. Tixier’s equation is mathematically documented as follows:

$$K_{Tixier} = 250 \frac{\varphi^3}{S_{wirr}} \tag{1}$$

Where  $K_{Tixier}$  = Tixier Permeability,  $\varphi$ = Porosity  $S_{wirr}$  = Irreducible water saturation.

##### B. Permeability Estimation by Timur Method

The second permeability equation used for this comparative study was proposed by Timur (1968). This equation is based on similar algorithm as that of Tixier (1949); although some variations exist between the duo. The earlier estimated irreducible water saturation was utilized to compute Timur’s permeability across 0.5 feet thickness of the bore wells; average values across each of the reservoirs were then taken.

$$K_{Timar} = 250 \frac{4.4}{S_{wirr}^2} \tag{2}$$

Where  $K_{Timar}$  = Timur Permeability,  $\varphi$ = Porosity,  $S_{wirr}$  = Irreducible water saturation.

##### C. Permeability Estimation by Coates and Dumanoir Method

Thirteen years after the emergence of Timur’s relation, Coates and Dumanoir proposed another relation that expressed the reservoir permeability as a direct function of the square porosity and a fraction of the irreducible water saturation.

$$K_{CD} = 100 \frac{\varphi^2(1-S_{wirr})}{S_{wirr}} \tag{3}$$

Where  $K_{CD}$  = Coates and Dumanoir Permeability,  $\varphi$ = Porosity,  $S_{wirr}$  = Irreducible water saturation.

#### V. DETERMINATION OF POROSITY

Porosity is the ratio of the total volume of pore space to the entire volume of the formation. It relates the amount of internal space in a given volume of rock to the total volume of rock in the reservoirs. The amount of internal space or voids in a given volume of rock determines the amount of fluid it will hold.

$$Total\ Porosity(\%) = \frac{volume\ of\ pore\ space}{total\ volume\ of\ formation} \times 100\% \tag{4}$$

Porosity may be classified as primary or inter-granular and secondary porosity. Primary porosity is the porosity that has existed in the formation since the time they were deposited. Secondary porosity is as a result of the action of tectonic forces or formation water. Porosity may be classified as effective and absolute porosity. Effective porosity is the porosity available to free fluid excluding unconnected porosity occupied by water bound and disseminated shale. Absolute porosity is the total porosity regardless of whether or not the individual voids are connected. Porosity was estimated from the density logs in this study.

##### A. Density Log Derived Porosity

Density log is a porosity log that measures electron density of a formation. It can assist the geologist to identify minerals, detect gas-bearing zones, determine hydrocarbon density and evaluated shaly sand reservoirs and complex lithologies.

$$Porosity(\varphi) = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \tag{5}$$

Where  $\rho_{ma}$  = matrix density,  $\rho_b$  = Formation’s bulk density and  $\rho_f$  = formation’s fluid density.

Effective porosity was calculated for evaluating interval using the equation shown below:

$$(\varphi)_e = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} - V_{sh} \left\{ \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \right\} \quad (6)$$

Where  $\rho_{ma}$ = matrix density (usually 2.66 g/cc sandstone),  $\rho_b$ = Formation’s bulk density (obtained from density log at 0.6ft. interval),  $\rho_f$ = formation’s fluid density (1.5 gm/cc for water and 0.8g/cc for hydrocarbon) and  $V_{sh}$ = Density of adjacent shale body.

**B. Determination of Irreducible Water Saturation ( $S_{wirr}$ )**

Irreducible water saturation is the water harbored in the pore spaces by capillary force. When a zone is at irreducible water saturation ( $S_{wirr}$ ), the water saturation in the uninvaded zone ( $S_w$ ) will not migrate because it is held by pressure in the grains. For most reservoir rocks in the field, irreducible water saturation ranges from values less than 10 % to values more than 50 % [13]. The ( $S_{wirr}$ ) was estimated from the equation below:

$$S_{wirr} = \sqrt{\frac{F}{2000}} \quad (7)$$

Where  $F$  = Formation factor and  $S_{wirr}$ = Irreducible water saturation.

The formation factor was estimated from the Achie’s equation below:

$$F = \frac{a}{\varphi^m} \quad (8)$$

Where  $\varphi$  = Porosity,  $a$  = Lithologic constant and  $M$  = Cementation exponent.

**VI. RESULTS AND DISCUSSION**

**A. Quantitative Analysis of Reservoir Permeability (K)**

Recorded average permeability across the fifteen reservoirs mapped out are shown in Tables II–IV.

Table II Average Porosity and Permeability Values Obtained for Well A Reservoirs

RSV	Porosity ( $\varphi$ )				Permeability (K)						
	Total $\varphi$ (v/v)	$\varphi_e$ (v/v)	NPH I (PU)	F	$R_w$ ( $\Omega m$ )	$S_w$ (v/v)	$K_{Tixier}$	$K_{Timur}$	$K_{CD}$	$K_{average}$	
RSV1	0.316	0.289	0.348	16.593	1.490	0.505	244056.900	86717.010	3529.742	11434.500	
RSV2	0.277	0.252	0.339	17.412	1.567	0.795	16549.980	9091.426	979.819	8873.743	
RSV3	0.271	0.236	0.337	21.269	0.191	0.461	75419.440	24987.480	1183.889	33863.600	
RSV4	0.261	0.234	0.323	21.946	0.197	0.564	6088.246	4095.484	654.461	3612.720	
RSV5	0.269	0.237	0.328	21.081	0.189	0.842	2885.773	2955.228	646.456	2160.486	

Table III Average Porosity and Permeability Values Obtained for Well B Reservoirs

RSV	Porosity ( $\varphi$ )				Permeability (K)						
	Total $\varphi$ (v/v)	$\varphi_e$ (v/v)	NPH I (PU)	F	$R_w$ ( $\Omega m$ )	$S_w$ (v/v)	$K_{Tixier}$	$K_{Timur}$	$K_{CD}$	$K_{average}$	
RSV1	0.256	0.246	0.366	18.895	0.151	0.166	57.378	7075.634	71.716	2401.576	
RSV2	0.246	0.231	0.301	20.334	0.162	0.305	41.883	4292.459	56.940	1463.761	
RSV3	0.234	0.222	0.288	21.013	0.168	0.271	29.210	1388.265	45.814	487.763	
RSV4	0.227	0.212	0.298	29.138	0.233	0.532	27.598	1395.567	42.829	488.664	
RSV5	0.219	0.204	0.277	1898.584	15.188	0.780	23.398	1065.497	37.746	375.547	

Table IV Average Porosity and Permeability Values Obtained for Well C Reservoirs

RSV	Porosity ( $\varphi$ )				Permeability (K)						
	Total $\varphi$ (v/v)	$\varphi_e$ (v/v)	NPH I (PU)	F	$R_w$ ( $\Omega m$ )	$S_w$ (v/v)	$K_{Tixier}$	$K_{Timur}$	$K_{CD}$	$K_{average}$	
RSV1	0.279	0.277	0.331	13.439	0.941	0.781	8.259	5810.766	9143.295	4987.440	
RSV2	0.275	0.267	0.320	17.453	1.221	0.980	7.757	5460.227	8620.817	4314.287	
RSV3	0.279	0.278	0.322	13.946	0.976	0.848	8.269	5757.388	9075.385	4947.014	
RSV4	0.274	0.271	0.320	14.941	1.311	0.987	7.931	5099.150	8085.388	4397.490	
RSV5	0.274	0.271	0.329	13.955	0.976	0.961	7.891	4954.188	7865.795	4275.958	

Permeability obtained in well A by Tixier method ranged from 244056.9 in Reservoir A to 2885.8 mD in Reservoir E. Similarly, Timur equation and Coates and Dumanoir equation yielded values that ranges from 86717.0 to 2955.2 mD and 3529.742 to 640.5 mD respectively. Generally, permeability in well A is observed to decrease with depth. This may not be unconnected with close grain parking owing to overburden loads. Tixier method was observed to yield highest permeability across the reservoirs of well A. This trend amazingly change in well B, with Tixier recording values less than 100 mD, although these values were observed to be very close in range to the results obtained from Coates and Dumanoir equation. Based on the findings from the Langbodo field, the Tixier method was also observed to yield ridiculously low permeability values in interval penetrated by reservoirs (A to E) of “Langbodo” well C. The mean permeability values across the reservoirs are tabulated along the triple set of permeability equations Fig. 2, 3 and 4 are graphical representation of the triple set of equation and the mean value. The inconsistency noticed in the values obtained from Tixier method is believed to be due to certain effects on the reservoirs. This may be hydrocarbon effect or probably presence of heterogeneities that masked through permeability as presented by the method. [14], [15] and [16], have variously recorded permeability for some Niger Delta reservoirs: and the values obtained by the author are far more than that obtained by the Tixier method in wells A and B. Since mean values are true representations of dataset, the average permeability values are preferred to the other methods. It is however noticed that close similarities exist between the average permeability value and the Timur’s permeability (Fig. 3 – 5).

Fig. 5 shows the comparison of the average permeability values to each of the values obtained from the triple set of equation across well A reservoirs.

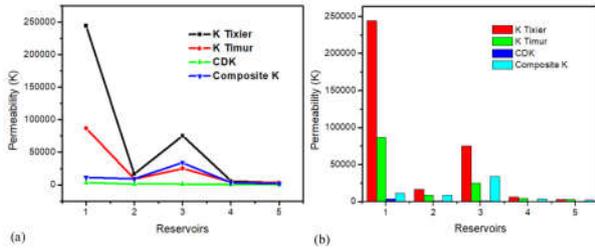


Fig. 3 (a and b) Comparison of Different Permeability Values Across Langbodo Well A

The reservoir permeability obtained from RSV 1 of well A dropped suddenly in RSV 2. It increased a little in RSV 3 and later dropped in RSV 4 and 5. This result might be attributed to predominant laminated shale deposits in reservoirs 2, 4 and 5 of well A. However, the Timur’s estimation model gave almost the same values with the Composite model which is a merger of the three other models. As earlier reported in this work, these discrepancies may be as a result certain heterogeneities such as shale/clay which masked through the permeability [16].

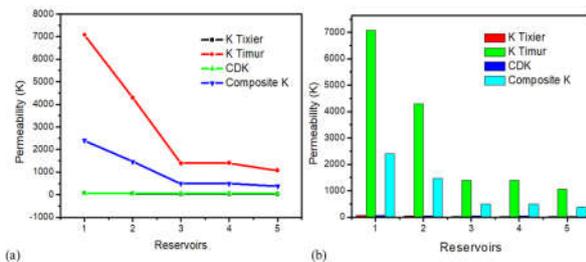


Fig. 4 (a and b) Comparison of Different Permeability Values Across Langbodo Well B

In well B, the Composite model was found to almost behave similar to the Timur’s estimation model. From this research we find higher estimated transmitivities and high reservoir permeability distribution within the models. The result from the Composite model shows a better representation of the permeability. This is similar to the work of [10], done by merging different models in the absence of core data from the study area to a nearby field core data in developing a reliable reservoir geophysical model. The differences in the behaviors of each of the models may be as a result of the permeability being masked by certain unnoticed heterogeneities [15].

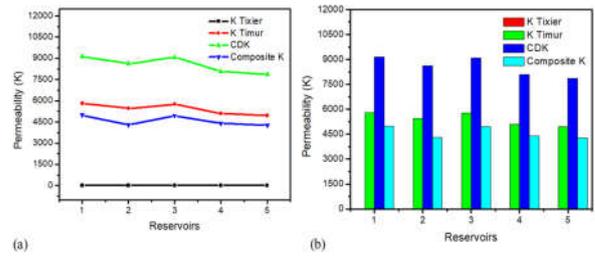


Fig. 5 (a and b) Comparison of Different Permeability Values Across Langbodo Well C

The three estimation models in well C for all the reservoirs behaved in almost similar ways. This may be as a result of similar deposits in each of the five reservoirs. It is evident from the Fig. 5 (a and b) above that the composite permeability estimation model which is obtained from the merger of the other three models employed in this work mirrors the Timur’s permeability model. Integration of the existing models to obtain a better reservoir permeability will give a better picture of the reservoirs in well C. This is similar to the work of [10].

*B. Discussion of Other Petrophysical Parameters*

Some other petrophysical parameters were evaluated, part of the results obtained from these are shown in Tables 4.1, 4.2 and 4.3. Other analyzed parameters such as the irreducible water saturation is tabulated in Table 4.4. Some of the important parameters evaluated are discussed below:

*1) Porosity*

Average values of porosity (Table II) obtained from the reservoirs of well A are, 0.3160, 0.2770, 0.2710, 0.2610 and 0.2690 for RSV 1, RSV 2, RSV 3, RSV 4 and RSV 5 respectively. These strongly suggest moderate to good porosity in the reservoir sands. The effective porosity values however reduced with noticeable differences with RSV 1, RSV 2, RSV 3, RSV 4 and RSV 5 recording values (measured in  $v/v$ ) of 0.289, 0.252, 0.236, 0.236, 0.234 and 0.237 respectively. The differences observed between the density porosity and the effective porosity is interpreted to be microporosity contributions from shale/clay. Similar trend to this is also observed in Well B (Table III) and Well C (Table IV).

*2) Irreducible Water Saturation  $S_{wirr}$*

Observed irreducible water saturation is range from 0.09 to 1 for Well A, 0.094 to 0.138 in Well B and 0.081 to 0.087 in Well C (Table V). These values are high enough to ensure little to no water cut during production.

Table V Irreducible Water Saturation ( $S_{wirr}$ ) in Langbodo Wells Reservoirs

Reservoirs	$S_{wirr}$ in Well A	$S_{wirr}$ in Well B	$S_{wirr}$ in Well C
RSV 1	0.088	0.094	0.081
RSV 2	0.092	0.099	0.087
RSV 3	0.100	0.101	0.081
RSV 4	0.100	0.111	0.084
RSV 5	0.092	0.138	0.083

## VII. CONCLUSION

Careful comparison of the Tixier, Timur and Coates and Dumanoir equations and the mean (composite) permeability shows that the Timur's relation closely agrees with the composite (mean) value, although some marked discrepancies were observed at some points. Petrophysically, subsurface reservoirs in the Langbodo field have reasonable hydrocarbon in their pore spaces, and estimated producibility indicators are good enough to support secondary migration of this oil into the borehole, if developed. Taking stand from the findings of this study, the use of a single method for estimating of reservoir permeability (K) is strongly discouraged. It is recommended that composite Permeability (K) equations be used.

## References

- [1] G. I. Alaminokuma and W. N. Ofuyah, "Petrophysical evaluation of reservoirs for hydrocarbon reserve estimation in eastern central swamp depobelt, Niger Delta", *Malaysian Journal of Geosciences*, vol. 4, no. 2, pp. 79 – 85, Apr. 2017.
- [2] F. Razavirad, M. Schmutz, and A. Binley, "Estimation of the permeability of hydrocarbon reservoir sample using induced polarization and nuclear magnetic resonance methods", *Geophysical Journal*, vol. 84, no. 2, DOI: 10.11901/GEO 0745.1. 2017.
- [3] J. J. Liu and J. C. Liu, "Permeability predictions for tight sandstone reservoir using explainable machine learning and particle swarm optimization", *Geofluid*, vol. 1, no. 1, pp. 1 – 15, Jan. 2022.
- [4] M. P. Tixier, "Evaluation of resistivity from electric log resistivity gradient", *Earth Science Journal*, vol. 2, no. 1, pp.113 – 138, Jan. 1949.
- [5] A. Timur, "An investigation of permeability, porosity and residual saturation for sandstones reservoirs", *Log Analyst*, vol. 9, no. 8, pp. 1 – 15, Dec. 1968.
- [6] G. R. Coates, J. L. Dumanoir, "A new approach to improved log derived permeability", *The Log Analyst*, vol. 6, no. 1, pp. 17 – 67, Sept. 1981.
- [7] M. L. W. Tuttle, R. R. Charpentier, and M. E. Brownfield, "Niger Delta petroleum system: Niger Delta province, Nigeria, Cameroon and Equatorial Guinea Africa", *United State Geological Survey*, vol. 2, no. 1, pp. 50 – 99, Mar. 2015.
- [8] B. Balan, S. Mohaghegh, and S. Ameri, "State of the art in permeability estimation determination in well log data, part 1", *Eastern regional Conference, Morgan town, Virginia, U.S.A.*, vol. 1, no. 2, pp. 17 – 21, Sept. 1995.
- [9] N. P. Singh, "Permeability prediction from wireline logging and core data: a case study from Assam-Arakan basin", *Springer*, vol. 9, no. 1, pp. 297 – 305, Jun. 2018.
- [10] I. Aigbedion and S. E. Iyayi, "A case study of permeability modelling reservoir performance in the absence of core data in the Niger Delta", *Journal of Applied Sciences*, vol. 7, no. 2, pp. 772 – 776, May. 2007.
- [11] K. Burke, "Longshore drift, submarine canyons and submarine fans in development of Niger Delta", *American Association of Petroleum Geologists Bulletin*, vol. 56, pp. 1975-1983, 1972.
- [12] K. C. Short and A. J. Stauble, "Outline of geology of Niger Delta", *American Petroleum Geologist Bulletin*, vol. 51, no. 2, pp. 761 – 779, May. 1967.
- [13] A. A. Said, M.E. Abdallah, and E. Alaa, "Applications of well logs to access the effects of clay minerals on petrophysical parameters of lower cretaceous reservoirs, North Sinai Egypt", *Egyptian Geophysical Society Journal*, vol. 1, no. 1, pp. 117-127, 2003.
- [14] O. A. Anyiam, "Reservoir characterization implications from petrophysical data of paradise field, Niger Delta", *Journal of Science and Technology*, vol. 8, no. 2, pp. 194 – 202, Nov. 2007.
- [15] O. A. Anyiam, A. W. Mode, and A. C. Ekwe, "Formation evaluation of an onshore appraisal well KG-5, Green field, Niger Delta, Nigeria", *American Journal of Scientific and industrial Research*, vol. 1, no. 2, pp. 262 – 270, Sept. 2011.
- [16] A. W. Mode, O. A. Anyiam, and E. J. Adepehin, "Petrophysical effect of clay heterogeneity on reservoir properties of Brown field, Niger Delta", *Lambert Publishing*, vol. 1, no. 2, pp. 11 – 25, Apr. 2013.