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Predicting Reservoir Permeability Using Core Data From Niger Delta Fields

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Abstract

The use of erroneous models can lead to inaccurate predictions of reservoir permeability. Most Niger Delta wells are uncored. Thus, there is need to do more research on how this challenge can be minimized . In this study, two hundred and thirteen core data points comprising of irreducible water saturation, permeability, and porosity sets were obtained from four different fields. Nine Permeability models were used to investigate the reliability of permeability predictions using core data. The laboratory permeability and porosity data were used to determine hydraulic zones using Amaefule et al recommended technique. Permeability predictions were made for each hydraulic unit using the nine existing models. A comparative analysis was carried out and standard errors were computed. Crystal Ball software was employed to find the degree of certainty for the predictions obtained.

In conclusion, Owolabi's model showed a distinctive characteristic within most of the flow zones. It performs better in high perm reservoirs. Tixier and Schlumberger permeability models were seen to predict better in low permeability zones.

Key words: Permeability Model, Certainty level, Hydraulic Units, Flow Zone Indicator, standard error of prediction, Crystalball Software, Monte Carlo Simulation, Model ranking and Prediction.

1.0 Introduction

Knowledge of the prevailing permeability value of a reservoir is a sine qua non to the overall productivity of a well. Over the years attempts have been made by different oil and gas Model developers to adequately derive a representative permeability model of a productive rock for future predictions.

According to Ofonmbuk et al. [1], "the permeability of a rock is one of the most important parameters necessary for effective reservoir characterization and management. Therefore accurate knowledge of its distribution in the reservoir is critical to accurate production performance prediction. During primary depletion, areal variation of permeability influences oil recovery. Permeability measurements from cores are direct measurement of these properties. But a reservoir without core data is often associated with uncertainties as these properties have to be log derived. Several authors have proposed models for permeability determination in an uncored reservoir using well logs. These models are based on correlation between permeability, porosity and irreducible water saturation being a function of the rock characteristics".

From the above excerpt, one can further confirm that determination of permeability models have been championed by diverse scholars. This is so because permeability is one petrophysical property that cannot be measured in situ either via coring or logging operation. Most of the permeability values that are used today are either got from the lab or derived. It is this derivable nature of this property that prompted the design of K-models, just as any other derived models in the field of science.

2.0 Problem Definition

This study is borne out of the unavailability of core data in most Niger Delta wells. This insufficiency is largely due to poor capital base. The need to establish the most acceptable reservoir perm/por/water saturation model that can give an approximate solutions become pertinent

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3.0 Technical Objective

The objectives of this study include;

1. To apply the principle of FZI in the analysis of the data
2. To carry out a comparative analysis between the actual k values (from coring techniques) and the predicted k values (from model)
3. To recommend with a level of certainty the models that predict better within Niger Delta province
4. To carry out model ranking
5. To validate our findings using Crystalball software and standard errors calculation

4.0 Literature Review

5.0 Historical Perspective On Permeability Models

Timur [2] established a relationship for estimating permeability and that of water saturation. This he did by testing several possibilities through the laboratory measurement of permeability (K), porosity (ϕ) and irreducible water saturation (S_{wi}) on 155 sandstone samples from three different oil fields in North America.

His empirical equation for permeability is one of those to be considered in this study.

Ofonmbuk et al. [1] used five empirical approaches to model the permeability of a reservoir without a core data in Niger Delta. The aim of their work was to use these equations to analyse their reservoir flow performance using a simulator in order to find out which of them could yield a higher oil recovery. It was eventually investigated that the permeability model generated using correlation from a nearby field core data yielded the highest recovery. The five empirical models they analyzed are Timur [2], Coates [3], Tixier [4], Udegbunam [5] and a model generated using a core data from a nearby field [1]. It is important to state here that all the five models were used in this study.

Amaefule et al. [3] presented a new, practical and theoretical methodology for identifying and characterizing hydraulic units within mappable geological units (facies). The technique is based on a modified Kozeny-Carmen equation and the concept of mean hydraulic radius.

Usman et al. [4] reviewed the commercially available permeability-estimation techniques and discussed the important factors that illustrate their relationship. They stated that detailed and accurate reservoir characterization demands the use of various measurements. Therefore, understanding the various permeability measurement techniques used by the industry is needed. Thus, the three major permeability measurement techniques are wireline-log analysis (including the RFT method), laboratory testing of core samples, and well testing; while the core and log techniques measure absolute permeability, well testing and RFT measured qualitatively permeability. In their work, different existing models were reviewed under each technique. Examples of such models are those of;

a. Modified Kozeny model [5,6]:

$$K = \frac{\text{¤}^3}{\left[5A_g^2(1-\text{¤})^2\right]} \text{..........................}(1)$$

b. With the introduction of the Coates-Dumanoir [7] relationship of the free-fluid model, a new equation was derived that ensured zero permeability at zero porosity and when $S_{wi} = 100\%$. Coates and Denoo [8] accommodated the two conditions with the following relationship:

$$k^{1/2} = 100\text{¤}_e^2\left[\frac{(1-S_{wi})}{S_{wi}}\right] \text{..................}(2)$$

c. Morris and Biggs [9] observed that it is easier to predict a rock's bulk-volume irreducible water, $V_{bwi} = \phi_t S_{wi}$, than the actual value of S_{wi}. This requires a slight modification of Coates and Denoo equation above, made by multiplying the numerator and denominator by total porosity, ϕ_t :

$$k^{1/2} = 100\text{¤}_e^2\left(\frac{\text{¤}_t - V_{bwi}}{V_{bwi}}\right) \text{...............}(3)$$

d. Usman et al [3] also presented an arithmetic averaging model relating core and log permeability to well-test permeability:

$$\frac{(\text{¦})_{wt}}{k_{rh\bar{h}}S_h} = \sum_{i=1}^{N} F_i \bar{k}_i h_i \text{...................}(4)$$

e. E.t.c

6.0 Basic Concept of Hydraulic Unit (Hu) [10]

Petroleum geologists, engineers, and hydrologists have long recognized the need of defining quasi geological/engineering units to shape the description of reservoir zones as storage containers and reservoir conduits for fluid flow. Several authors have various definitions of flow units, which are resultant of the depositional environment and digenetic process. Bear [11] defined the hydraulic (pore geometrical) units as the representative elementary volume of the total reservoir rock within which the geological and petrophysical properties of the rock volume are the same. Ebanks [12] defined hydraulic flow units as a mappable portion of the reservoir within which the geological and petrophysical properties that affect the flow of fluid are consistent and predictably different from the properties of the other reservoir rock volume. Hearn et al. [13] defined flow unit as a reservoir zone that is laterally and vertically continuous, and has similar permeability, porosity, and bedding characteristics. Gunter et al. [14] defined flow unit as a stratigraphically continuous interval of similar reservoir process that honors the geologic framework and maintains the characteristics of the rock type.

From these definitions the flow units have the following characteristics:

- A flow unit is a specific volume of reservoir, composed of one or more reservoir quality lithology
- A flow unit is correlative and map able at the interval scale
- A flow unit zonation is recognizable on wire-line log
- A flow unit may be in communication with other flow units

Amaefule et al. [3] defined hydraulic units as distinct zones in a reservoir with similar fluid flow characteristics. They developed a new, practical and theoretically- based technique to identify and characterize units with similar pore throat geometrical attributes (hydraulic units).

7.0 Monte Carlo Simulation Steps [15]

- Building a spreadsheet model to describe an uncertain situation
- Define assumptions distributions for inputs with uncertainty
- Define a Forecast and Run a Simulation on the model to randomly generate values of uncertain variables over and over to simulate the model outcome or output.
- Analyze the results which show the entire range of all possible outcomes and the likelihood of the occurrence of each of them.

8.0 The Crystal ball Software [15]

9.0 Use of Crystal Ball

- A forecasting tool for the determination of certainty level within a given range
- Sensitivity analysis using spider and tornado chart
- Use generally for risk analysis in decision making involving cost

10.0 Simulation Using Crystal ball [15].

- Set run preferences for your simulation
- Trials , sampling, speed, options, statistics
- Run the simulation
- Analyze Crystal Ball results
- Assumption charts
- Forecast charts
- Trend, sensitivity, or scatter charts

11.0 Methodology

Figure 1 below shows a flow chart of the steps embarked upon in actualizing the goals of this study. At this point each of the steps shall be briefly discussed and a deeper touch shall be thrown on some of the seemingly new concepts.

12.0 Model Identification & Selection

As previously mentioned, a lot of models were identified. Based on some inherent constraints, nine models were selected from the lot. The selected permeability models are;

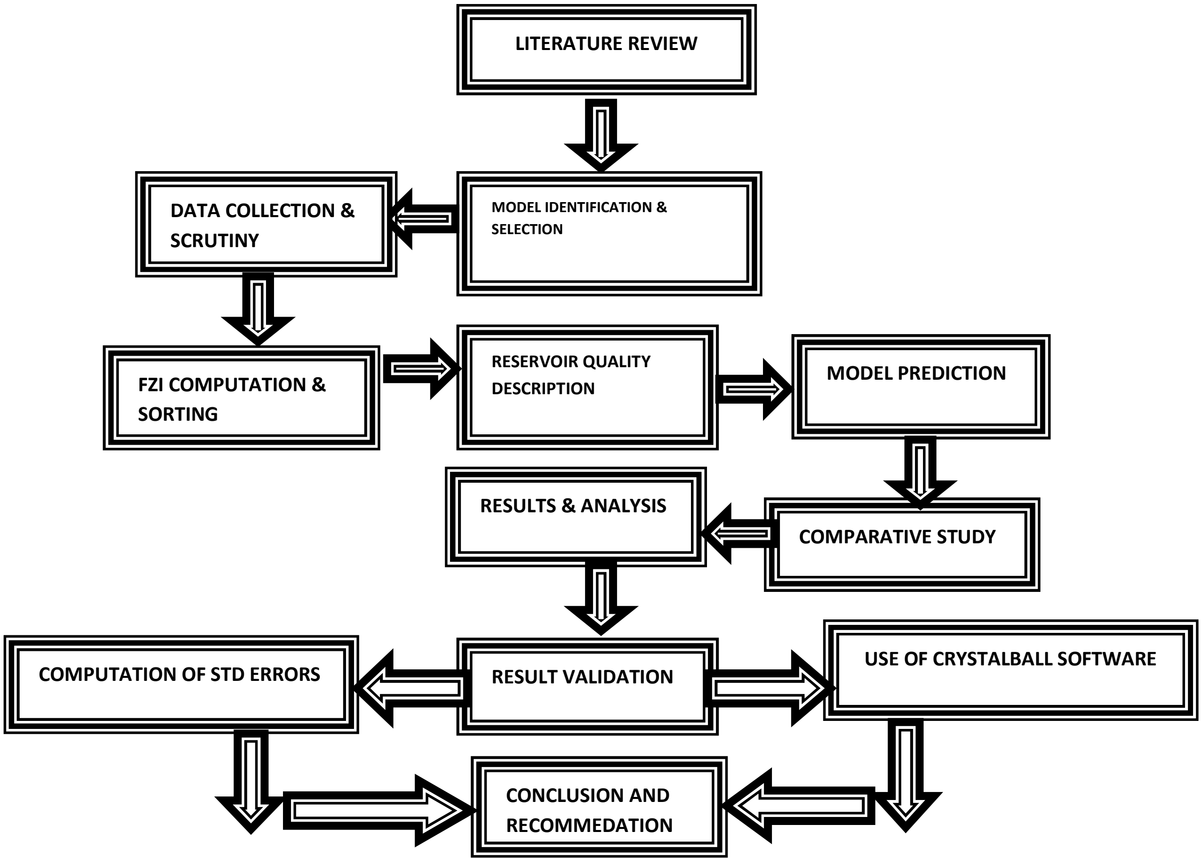

Fig 1: Schematics of Methodology

I. TIXIER K MODEL [16]

$$K^{1/2} = 250\frac{¤^{3}}{S_{wi}}\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

II. SCHLUMBERGER ORGANISATION [17]

$$K = 6.25*10^{-4}\frac{¤^{6}}{S_{wi}^{2}}\ldots\ldots\ldots\ \ldots\ldots\ldots\ .(6)$$

III. TIMUR K MODEL [2]

$$K = 0.136\frac{¤^{4.4}}{S_{wi}^{2}}\ldots\ldots\ldots\ldots\ldots(7)$$

IV. COATES and Denoo K MODEL [8]

$$K^{1/2} = 100\frac{¤_{e}^{2}\left(1 - S_{wi}\right)}{S_{wi}}\ldots\ldots\ldots\ldots(8)$$

V. UDEGBUNAM [18]

$$LogK = -0.83565 + 13.068¤\ldots\ldots\ldots\ldots(9)$$

VI. OWOLABI ET AL [17]

$$K = 307 + 26552¤^{2} - 34540\left(¤ * S_{wi}\right)^{2}\ldots\ldots\ldots\ldots\ldots(10)$$

VII. MODIFIED COATES AND DENOO [17]

$$K_{h} = \left(1.68*10^{4}\right)*¤^{3}*\frac{\left(1 - S_{wi}\right)^{1.2}}{S_{wi}^{1.2}}\ldots\ldots\ldots\ldots\ldots(11)$$

VIII. ADJUSTED TIMUR K MODEL [17]

$$K = \frac{10^4 ¤^3}{S_{wi}^{1.4}} .... (12)$$

IX. OFONMBUK K MODEL [1]

$$K = 18044 * ¤^{3.104} .... (13)$$

13.0 Data Collection And Scrutiny

After the review of the relevant texts and papers, data was sourced for, gathered and a quality check on each data points were carried out.

14.0 Data Description

213 data sets consisting of K, ¤ and S_{wi} were obtained from fields SARI, A-B-O & N-S of company X & Y located in Niger Delta. The table below shows a typical raw core data from a field in Niger Delta (WELL ABO). These data sets were among those used for analysis.

Table 1: Raw Core Data from Well A-B-O Located In Niger Delta

		COMPANY X	**WELL : A-B-0**		
S/N	**DEPTH (m)**	**Horiz. Perm. (mD)**	**Horiz. Klink K (mD)**	**Swi (%)**	**Porosity(%)**
	2230	Shale- No Plug	Taken		
1	2230.25	3490	3380	6.40	30.20
2	2230.5	4240	4120	18.20	28.90
3	2230.8	2320	2240	12.30	30.10
4	2231.25	4630	4500	2.50	34.50
5	2231.5	4340	4210	4.00	32.00
6	2231.75	4670	4540	3.60	28.70
7	2232	1680	1610	16.50	28.10
8	2232.6	6800	6640	3.00	31.90
9	2232.82	3920	3800	8.80	34.10
10	2233	4450	4320	7.20	35.10
11	2233.25	4180	4060	8.30	35.40
12	2233.5	5240	5100	7.10	35.50
13	2233.75	2870	2770	13.00	32.00
14	2234	4300	4180	6.60	35.10
15	2234.25	4980	4850	3.80	35.10
16	2234.5	5310	5170	1.60	34.80
17	2234.73	5040	4900	2.70	35.20
18	2235	5040	4910	4.90	34.70
19	2235.25	4520	4400	7.90	33.60
20	2235.5	4870	4740	3.60	34.10
21	2235.75	4450	4330	5.60	34.10
22	2236.1	3890	3780	3.90	35.00
23	2236.25	5160	5020	3.80	34.50
24	2236.5	3270	3160	2.90	34.10
25	2236.65	4570	4450	4.60	34.40
26	2237	4010	3890	7.60	35.10
27	2237.25	281	259	36.10	25.20
28	2238	4550	4420	2.10	35.00
29	2238.3	3110	3010	5.20	34.20
30	2238.5	1990	1920	16.30	33.50
31	2238.75	3470	3360	7.10	35.50
32	2239	3800	3680	14.70	35.00
33	2239.25	2500	2410	6.30	35.10
34	2239.5	4260	4140	3.10	35.10
35	2239.75	4210	4090	4.10	35.20
36	2240	3640	3530	6.90	35.50
37	2240.25	2990	2890	10.80	34.80
38	2240.5	2590	2500	14.00	34.40
39	2240.75	2590	2500	11.20	33.80
40	2241.08	368	342	19.40	29.20
41	2241.93	0.293	0.201	93.50	14.50
42	2242	0.255	0.177	82.20	14.10
43	2242.45	0.196	0.141	89.50	14.80
44	2242.75	0.092	0.066	83.50	14.90
45	2242.95	0.222	0.161	93.30	13.40
46	2243	0.03	0.02	83.40	13.00
47	2244.45	0.053	0.036	55.30	13.10
48	2246.95	5790	5640	4.80	33.70
49	2247.75	0.733	0.543	80.00	14.10
50	2247.95	0.392	0.28	96.10	13.60

14.0 FZI Computation

As earlier explained and summarized in the chart below, the flow zone indicators were identified following the recommendation of Jude Amaefule [3]. This action became necessary in order for us to adequately analyze our findings. The big question that prompted the incorporation of this technique into this work was “could it be that some models will predict better in certain zones than others?” In this work, we however excluded the identification of hydraulic units (HU).

After the computation of FZI, the data points were sorted and then zoned according to the computed FZI values.

The table below shows a permeability quality description for each data set according to their mean FZI values. This is a modified version of Tiab et al. [10] and Hassan et al. [19] descriptions.

Table 2: Reservoir Quality Description In Terms Of FZI

MEAN FZI VALUES	QUALITATIVE NAME
>8.00	EXTRAORDINARY QUALITY RESERVOIR (EQR)
7.00 – 7.99	EXTRA EXTRA GOOD QUALITY RESERVOIR (EEGQR)
6.00 – 6.99	EXTRA GOOD QUALITY RESERVOIR (EGQR)
5.00 – 5.99	VERY GOOD QUALITY RESERVOIR (VGQR)
4.00 – 4.99	GOOD QUALITY RESERVOIR (GQR)
3.00 – 3.99	MEDIUM QUALITY RESERVOIR(MQR)
2.00 – 2.99	LOW QUALITY RESERVOIR(LQR)
1.00 – 1.99	VERY LOW QUALITY RESERVOIR(VLQR)
<0.99	EXTREMELY LOW QUALITY RESERVOIR(ELQR)

15.0 Model Prediction and Comparative Study

Each of the models was used for permeability prediction using the 213 core data points obtained for each hydraulic unit. Using the **ARITHMETIC AVERAGE** statistical concept, the mean of the predicted K- value for each FZI zone was compared to the actual field data and the degree of variation/ standard error was computed.

16.0 Analysis Of Result And Validation

With the surprising and wonderful results obtained, critical analyses were carried out. As stated earlier, standard error of predictions associated in the use of each model was calculated. This approach became pertinent in order to find out the model that has the lowest error/ variation; since the closer the predicted values are to the actual, the lower the error /variation. The model below was used for the standard error of prediction computation:

$$S_{ep} = \sqrt{\frac{\left(Y_I - Y_{pred}\right)^2}{N}} \quad \text{....................}(14)$$

Furthermore, the CRYSTALBALL software was used to validate our result by checking the degree of CERTAINTY LEVEL of each model’s prediction. The model that shows the highest certainty level should output the lowest error of prediction. If this is true our result is validated

17.0 Results and Discussion

Table 3: FZI Computation

		COMPANY: X			WELL:ABO				
S/N	**DEPTH (m)**	**HorKair**	**Hor Klink K**	**Swi(%)**	**Por (%)**	**Por frac**	**NPI**	**RQI**	**FZI**
1	2230.25	3490	3380	6.40	30.20	0.3020	0.4327	3.3219	7.6777
2	2230.5	4240	4120	18.20	28.90	0.2890	0.4065	3.7491	9.2236
3	2230.8	2320	2240	12.30	30.10	0.3010	0.4306	2.7088	6.2904
4	2231.25	4630	4500	2.50	34.50	0.3450	0.5267	3.5861	6.8085
5	2231.5	4340	4210	4.00	32.00	0.3200	0.4706	3.6016	7.6534
6	2231.75	4670	4540	3.60	28.70	0.2870	0.4025	3.9493	9.8112
7	2232	1680	1610	16.50	28.10	0.2810	0.3908	2.3768	6.0815
8	2232.6	6800	6640	3.00	31.90	0.3190	0.4684	4.5302	9.6711
9	2232.82	3920	3800	8.80	34.10	0.3410	0.5175	3.3147	6.4058
10	2233	4450	4320	7.20	35.10	0.3510	0.5408	3.4835	6.4410
11	2233.25	4180	4060	8.30	35.40	0.3540	0.5480	3.3627	6.1365
12	2233.5	5240	5100	7.10	35.50	0.3550	0.5504	3.7636	6.8380
13	2233.75	2870	2770	13.00	32.00	0.3200	0.4706	2.9214	6.2080
14	2234	4300	4180	6.60	35.10	0.3510	0.5408	3.4266	6.3358
15	2234.25	4980	4850	3.80	35.10	0.3510	0.5408	3.6910	6.8247
16	2234.5	5310	5170	1.60	34.80	0.3480	0.5337	3.8272	7.1706
17	2234.73	5040	4900	2.70	35.20	0.3520	0.5432	3.7047	6.8201
18	2235	5040	4910	4.90	34.70	0.3470	0.5314	3.7351	7.0289
19	2235.25	4520	4400	7.90	33.60	0.3360	0.5060	3.5932	7.1009
20	2235.5	4870	4740	3.60	34.10	0.3410	0.5175	3.7020	7.1544
21	2235.75	4450	4330	5.60	34.10	0.3410	0.5175	3.5383	6.8380
22	2236.1	3890	3780	3.90	35.00	0.3500	0.5385	3.2632	6.0602
23	2236.25	5160	5020	3.80	34.50	0.3450	0.5267	3.7877	7.1911
24	2236.5	3270	3160	2.90	34.10	0.3410	0.5175	3.0227	5.8415
25	2236.65	4570	4450	4.60	34.40	0.3440	0.5244	3.5713	6.8105
26	2237	4010	3890	7.60	35.10	0.3510	0.5408	3.3056	6.1121
27	2237.25	281	259	36.10	25.20	0.2520	0.3369	1.0067	2.9880
28	2238	4550	4420	2.10	35.00	0.3500	0.5385	3.5286	6.5532
29	2238.3	3110	3010	5.20	34.20	0.3420	0.5198	2.9458	5.6676
30	2238.5	1990	1920	16.30	33.50	0.3350	0.5038	2.3772	4.7188
31	2238.75	3470	3360	7.10	35.50	0.3550	0.5504	3.0548	5.5503
32	2239	3800	3680	14.70	35.00	0.3500	0.5385	3.2197	5.9795
33	2239.25	2500	2410	6.30	35.10	0.3510	0.5408	2.6019	4.8109
34	2239.5	4260	4140	3.10	35.10	0.3510	0.5408	3.4102	6.3054
35	2239.75	4210	4090	4.10	35.20	0.3520	0.5432	3.3847	6.2309
36	2240	3640	3530	6.90	35.50	0.3550	0.5504	3.1311	5.6890
37	2240.25	2990	2890	10.80	34.80	0.3480	0.5337	2.8615	5.3611
38	2240.5	2590	2500	14.00	34.40	0.3440	0.5244	2.6768	5.1046
39	2240.75	2590	2500	11.20	33.80	0.3380	0.5106	2.7005	5.2891
40	2241.08	368	342	19.40	29.20	0.2920	0.4124	1.0746	2.6056
41	2241.93	0.293	0.201	93.50	14.50	0.1450	0.1696	0.0370	0.2180
42	2242	0.255	0.177	82.20	14.10	0.1410	0.1641	0.0352	0.2143
43	2242.45	0.196	0.141	89.50	14.80	0.1480	0.1737	0.0306	0.1764
44	2242.75	0.092	0.066	83.50	14.90	0.1490	0.1751	0.0209	0.1194
45	2242.95	0.222	0.161	93.30	13.40	0.1340	0.1547	0.0344	0.2224
46	2243	0.03	0.02	83.40	13.00	0.1300	0.1494	0.0123	0.0824
47	2244.45	0.053	0.036	55.30	13.10	0.1310	0.1507	0.0165	0.1092
48	2246.95	5790	5640	4.80	33.70	0.3370	0.5083	4.0621	7.9917
49	2247.75	0.733	0.543	80.00	14.10	0.1410	0.1641	0.0616	0.3754
50	2247.95	0.392	0.28	96.10	13.60	0.1360	0.1574	0.0451	0.2862

Table 4: Qualitative Description Of The Data Set After Sorting

COMPANY: X WELL: A-B-0

FLOW ZONE INDICATOR/UNITIZATION DATA

S/N	**DEPTH (meters)**	**Kair (mD)**	**Hor Klink K (mD)**	**Swi (%)**	**Por(%)**	**Por frac**	**NPI**	**RQI**	**FZI**
			ELQR						
46	2243.00	0.03	**0.02**	83.40	13.00	0.1300	0.1494	0.0123	0.0824
47	2244.45	0.053	**0.036**	55.30	13.10	0.1310	0.1507	0.0165	0.1092
44	2242.75	0.092	**0.066**	83.50	14.90	0.1490	0.1751	0.0209	0.1194
43	2242.45	0.196	**0.141**	89.50	14.80	0.1480	0.1737	0.0306	0.1764
42	2242.00	0.255	**0.177**	82.20	14.10	0.1410	0.1641	0.0352	0.2143
41	2241.93	0.293	**0.201**	93.50	14.50	0.1450	0.1696	0.0370	0.2180
45	2242.95	0.222	**0.161**	93.30	13.40	0.1340	0.1547	0.0344	0.2224
50	2247.95	0.392	**0.28**	96.10	13.60	0.1360	0.1574	0.0451	0.2862
49	2247.75	0.733	**0.543**	80.00	14.10	0.1410	0.1641	0.0616	0.3754
			GQR						
40	2241.08	368	**342**	19.40	29.20	0.2920	0.4124	1.0746	2.6056
27	2237.25	281	**259**	36.10	25.20	0.2520	0.3369	1.0067	2.9880
30	2238.50	1990	**1920**	16.30	33.50	0.3350	0.5038	2.3772	4.7188
33	2239.25	2500	**2410**	6.30	35.10	0.3510	0.5408	2.6019	4.8109
38	2240.50	2590	**2500**	14.00	34.40	0.3440	0.5244	2.6768	5.1046
39	2240.75	2590	**2500**	11.20	33.80	0.3380	0.5106	2.7005	5.2891
37	2240.25	2990	**2890**	10.80	34.80	0.3480	0.5337	2.8615	5.3611
31	2238.75	3470	**3360**	7.10	35.50	0.3550	0.5504	3.0548	5.5503
29	2238.30	3110	**3010**	5.20	34.20	0.3420	0.5198	2.9458	5.6676
36	2240.00	3640	**3530**	6.90	35.50	0.3550	0.5504	3.1311	5.6890
24	2236.50	3270	**3160**	2.90	34.10	0.3410	0.5175	3.0227	5.8415
32	2239.00	3800	**3680**	14.70	35.00	0.3500	0.5385	3.2197	5.9795
			EGQR						
22	2236.10	3890	**3780**	3.90	35.00	0.3500	0.5385	3.2632	6.0602
7	2232.00	1680	**1610**	16.50	28.10	0.2810	0.3908	2.3768	6.0815
26	2237.00	4010	**3890**	7.60	35.10	0.3510	0.5408	3.3056	6.1121
11	2233.25	4180	**4060**	8.30	35.40	0.3540	0.5480	3.3627	6.1365
13	2233.75	2870	**2770**	13.00	32.00	0.3200	0.4706	2.9214	6.2080
35	2239.75	4210	**4090**	4.10	35.20	0.3520	0.5432	3.3847	6.2309
3	2230.80	2320	**2240**	12.30	30.10	0.3010	0.4306	2.7088	6.2904
34	2239.50	4260	**4140**	3.10	35.10	0.3510	0.5408	3.4102	6.3054
14	2234.00	4300	**4180**	6.60	35.10	0.3510	0.5408	3.4266	6.3358
9	2232.82	3920	**3800**	8.80	34.10	0.3410	0.5175	3.3147	6.4058
10	2233.00	4450	**4320**	7.20	35.10	0.3510	0.5408	3.4835	6.4410
28	2238.00	4550	**4420**	2.10	35.00	0.3500	0.5385	3.5286	6.5532
4	2231.25	4630	**4500**	2.50	34.50	0.3450	0.5267	3.5861	6.8085
25	2236.65	4570	**4450**	4.60	34.40	0.3440	0.5244	3.5713	6.8105
17	2234.73	5040	**4900**	2.70	35.20	0.3520	0.5432	3.7047	6.8201
15	2234.25	4980	**4850**	3.80	35.10	0.3510	0.5408	3.6910	6.8247
21	2235.75	4450	**4330**	5.60	34.10	0.3410	0.5175	3.5383	6.8380
12	2233.50	5240	**5100**	7.10	35.50	0.3550	0.5504	3.7636	6.8380
			EEGQR						
18	2235.00	5040	**4910**	4.90	34.70	0.3470	0.5314	3.7351	7.0289
19	2235.25	4520	**4400**	7.90	33.60	0.3360	0.5060	3.5932	7.1009
20	2235.50	4870	**4740**	3.60	34.10	0.3410	0.5175	3.7020	7.1544
16	2234.50	5310	**5170**	1.60	34.80	0.3480	0.5337	3.8272	7.1706
23	2236.25	5160	**5020**	3.80	34.50	0.3450	0.5267	3.7877	7.1911
5	2231.50	4340	**4210**	4.00	32.00	0.3200	0.4706	3.6016	7.6534
1	2230.25	3490	**3380**	6.40	30.20	0.3020	0.4327	3.3219	7.6777
48	2246.95	5790	**5640**	4.80	33.70	0.3370	0.5083	4.0621	7.9917

			EQR						
2	2230.50	4240	**4120**	18.20	28.90	0.2890	0.4065	3.7491	9.2236
8	2232.60	6800	**6640**	3.00	31.90	0.3190	0.4684	4.5302	9.6711
6	2231.75	4670	**4540**	3.60	28.70	0.2870	0.4025	3.9493	9.8112

18.0 Results of Permeability Predictions from the Nine Existing Models for Each FZI Zones (Well ABO)

Table 5: Permeability Predictions For ELQR

			ELQR								
RAW CORE DATA SET			**PERMEABILITY PREDICTIONS FROM EXISTING MODELS**								
Horiz. Klink K (mD)	**Swi (%)**	**Por (%)**	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**	**(g)**	**(h)**	**(i)**
0.02	83.40	13.00	0.43	0.43	1.56	0.11	7.30	349.71	6.15	28.33	32.06
0.04	55.30	13.10	1.03	1.03	3.67	1.92	7.52	581.39	46.99	51.52	32.84
0.07	83.50	14.90	0.98	0.98	2.83	0.19	12.93	361.83	9.17	42.58	48.97
0.14	89.50	14.80	0.82	0.82	2.39	0.07	12.54	282.57	4.55	37.86	47.95
0.18	82.20	14.10	0.73	0.73	2.29	0.19	10.16	370.90	8.78	36.88	41.26
0.20	93.50	14.50	0.66	0.66	2.00	0.02	11.46	230.39	2.20	33.49	45.00
0.16	93.30	13.40	0.42	0.42	1.42	0.02	8.23	243.89	1.81	26.51	35.23
0.28	96.10	13.60	0.43	0.43	1.43	0.01	8.74	208.11	0.93	26.60	36.88
0.54	80.00	14.10	0.77	0.77	2.42	0.25	10.16	395.40	10.67	38.31	41.26

LEGENDS

(a) TIXIER K MODEL [16] (b) SCHLUMBEGER K MODEL [17] (c) TIMUR K MODEL [2] (d) COATES & DENOO K MODEL [8] (e) UDEGBUNAM K MODEL [18] (f) OWOLABI K MODEL [17] (g) MODIFIED COATES & DENOO K MODEL [17] (h) MODIFIED TIMUR K MODEL [17] (i) OFONMBUK K MODEL [1]

Table 6: Permeability Predictions For EGQR

			EGQR								
RAW CORE DATA SET			**PERMEABILITY PREDICTIONS FROM EXISTING MODELS**								
Klink K_H (mD)	**Swi (%)**	**Por (%)**	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**	**(g)**	**(h)**	**(i)**
3780	3.90	35.00	75536.88	75536.88	55630.00	91114.97	5472.05	3553.18	451494.29	40245.16	693.62
1610	16.50	28.10	1130.19	1130.19	1182.71	1596.73	686.21	2329.32	11027.68	2764.66	350.85
3890	7.60	35.10	20234.64	20234.64	14834.16	22435.99	5639.21	3553.65	114395.73	15950.79	699.79
4060	8.30	35.40	17854.32	17854.32	12912.11	19168.83	6171.94	3604.57	97500.33	14464.40	718.52
2770	13.00	32.00	3970.94	3970.94	3375.30	4696.26	2218.76	2966.15	27561.04	5700.71	525.19
4090	4.10	35.20	70724.24	70724.24	51612.98	83992.43	5811.47	3589.70	414526.11	38170.74	705.99
2240	12.30	30.10	3072.34	3072.34	2880.19	4173.06	1252.62	2665.29	25870.10	5126.63	434.31
4140	3.10	35.10	121618.41	121618.41	89159.34	148303.92	5639.21	3574.14	727940.32	55977.69	699.79
4180	6.60	35.10	26830.88	26830.88	19669.91	30397.25	5639.21	3559.70	153659.36	19433.89	699.79
3800	8.80	34.10	12689.40	12689.40	9743.00	14522.52	4173.86	3363.39	77019.53	11912.07	639.74
4320	7.20	35.10	22545.39	22545.39	16528.19	25215.03	5639.21	3556.17	128121.85	17205.05	699.79
4420	2.10	35.00	260525.17	260525.17	191866.75	326136.17	5472.05	3557.75	1592260.26	95740.82	693.62
4500	2.5	34.5	168622.1	168622.1	127075.817	215479.3	4707.71	3464.8	1070759.9	71835.9	663.3
4450	4.6	34.4	48945.75	48945.75	37057.8648	60230.28	4568.17	3440.4	305440.76	30325.9	657.4
4900	2.7	35.2	163082.9	163082.9	119014.287	199374.1	5811.47	3593.8	972624.38	68504.4	706
4850	3.8	35.1	80938.57	80938.57	59336.6506	97277.28	5639.21	3572.1	480256.8	42094.4	699.8
4330	5.6	34.1	31335.04	31335.04	24059.252	38422.49	4173.86	3381.9	198226.98	22428.5	639.7
5100	7.1	35.5	24816.09	24816.09	17865.985	27191.19	6360.48	3631.3	136488.64	18152	724.8

Table 7: Permeability Predictions for EEGQR

EEGQR											
RAW CORE DATA SET			**PERMEABILITY PREDICTIONS FROM EXISTING MODELS**								
Klink K_H (mD)	**Swi (%)**	**Por (%)**	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**	**(g)**	**(h)**	**(i)**
4910	4.90	34.70	45442.76	45442.76	33930.98	54611.84	4999.72	3494.11	275246.73	28491.41	675.33
4400	7.90	33.60	14409.92	14409.92	11328.63	17322.96	3590.86	3280.28	92509.11	13253.78	611.07
4740	3.60	34.10	75823.06	75823.06	58217.45	96954.19	4173.86	3389.29	491880.79	41633.18	639.74
5170	1.60	34.80	433626.20	433626.20	322290.58	554711.55	5152.45	3521.48	2712696.25	137711.36	681.39
5020	3.80	34.50	72983.96	72983.96	55001.65	90794.46	4707.71	3461.42	456046.85	39972.40	663.32
4210	4.00	32.00	41943.04	41943.04	35651.58	60397.98	2218.76	3020.27	327615.71	29686.98	525.19
3380	6.40	30.20	11576.09	11576.09	10794.67	17791.78	1290.88	2715.75	104352.10	12923.16	438.81
5640	4.80	33.70	39735.34	39735.34	31090.52	50735.39	3700.55	3313.45	263075.77	26862.84	616.73

Table 8: Permeability Predictions for EQR

EQR											
RAW CORE DATA SET			**PERMEABILITY PREDICTIONS FROM EXISTING MODELS**								
Klink K_H (mD)	**Swi (%)**	**Por (%)**	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**	**(g)**	**(h)**	**(i)**
4120	18.20	28.90	1099.32	1099.32	1099.88	1409.14	872.98	2429.09	9619.75	2621.76	382.79
6640	3.00	31.90	73178.18	73178.18	62513.73	108258.92	2152.99	3005.79	584204.51	43994.90	520.11
4540	3.60	28.70	26950.47	26950.47	27265.55	48649.31	821.99	2490.37	293252.96	24821.17	374.63

19.0 Analysis of Result

The tables below show a comparative study of all the models at a glance. Table 9 shows the average predictions of each model as compared to the actual horizontal klinkenberg corrected core permeability values while Table 10 summarizes the standard error of prediction.

Table 9: Summary of Results showing the Comparative Study of Average Permeability Predictions between the Nine Models

PERMEABILITY MODELS										
	CORE KLINK PERM	**TIXIER [16]**	**SCHLUM [17]**	**TIMUR [2]**	**COATES & DENOO [8]**	**UDEGBUNAM [18]**	**OWOLABI [17]**	**MODIFIED COATES & DENOO [17]**	**MODIFIED TIMUR [17]**	**OFONMBUK [1]**
ELQR	0.18	0.70	0.70	2.22	0.31	9.89	336.02	10.14	35.79	40.16
GQR	2463.42	22199.46	22199.46	16743.14	26665.41	4214.02	3214.25	135983.07	14798.98	611.71
EGQR	3968.33	64137.41	64137.41	47433.58	78318.21	4726.48	3386.51	388065.22	32001.87	647.34
EEGQR	4683.75	91942.54	91942.54	69788.26	117915.02	3729.35	3274.50	590427.91	41316.89	606.45
EQR	5100.00	33742.66	33742.66	30293.05	52772.46	1282.65	2641.75	295692.41	23812.61	425.84

Table 10: Results of Standard Error of Prediction For The Nine Existing Models For Each FZI Zones (WELL ABO)
From the results obtained above, one can affirm the following:

- For **extremely low quality reservoir zone** (low permeability zones), **Owolabi's** model had the highest error of prediction while **Tixier and Schlumberger's models**, two distinct models that are outputting exactly the same predictions, gave the lowest permeability variations.
- For **good quality reservoir zone**, **modified Coates and Denoo's** model has the highest error of prediction while **Owolabi's** model gave the lowest variation.
- For **extra good quality reservoir zone**, **modified Coates and Denoo's model** has the highest error of prediction while **Owolabi's model**, gave the lowest variation.
- For **extra extra good quality reservoir zone**, **modified Coates and Denoo's model** has the highest error of prediction while **Owolabi's model** gave the lowest variation.
- For **extraordinary quality reservoir zone**, **modified Coates and Denoo's model** gave the highest error of prediction while **Owolabi's model** gave the lowest.
- Ofonmbuk et al. [1] permeability model has the highest predictive limitation in that it cannot predict more than 1802md (assuming a cubic packing configuration for the field). From Table 9, one can see that it has the lowest range of permeability predictions.
- Furthermore, from their average values of prediction (Table 9) Tixier [16], Schlumberger [17], Timur [2], Coates et al. [8], modified Coates et al. [17] and modified Timur [17] models are all over predictive. Owolabi [17], Udegbunam [18] and Ofonmbuk's [1] models are under predictive.

20.0 Result Validation

213 data points from three Niger delta fields own by two companies were keyed into THE CRYSTALLBALL SOFTWARE. A permeability range typical of most Niger Delta reservoir was chosen
(**1800MD - 3000MD**). The charts below display our findings.

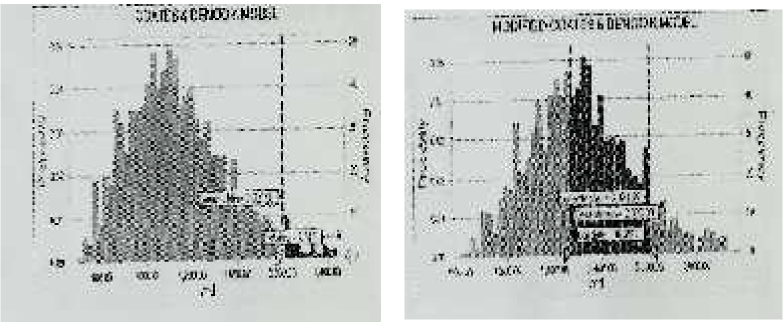

Figure 2: Certainty Level for Coates and Denoo [8] And Modified Coates & Denoo K model [17] Predictions within A Permeability Range Of 1800md & 3000md

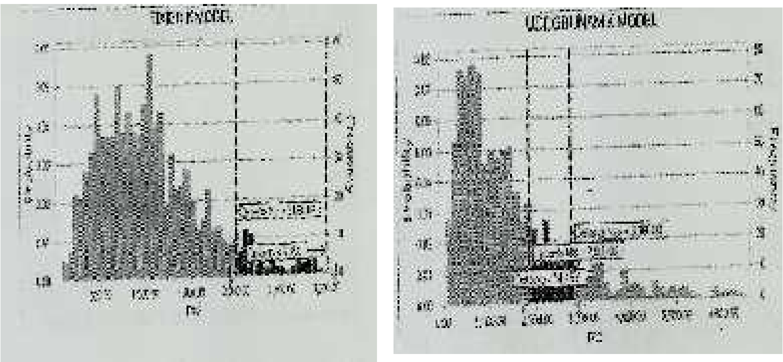

Figure 3: Certainty Level for Tixier [16] And Udegbunam K model [18] Predictions within A Permeability Range Of 1800md & 3000md

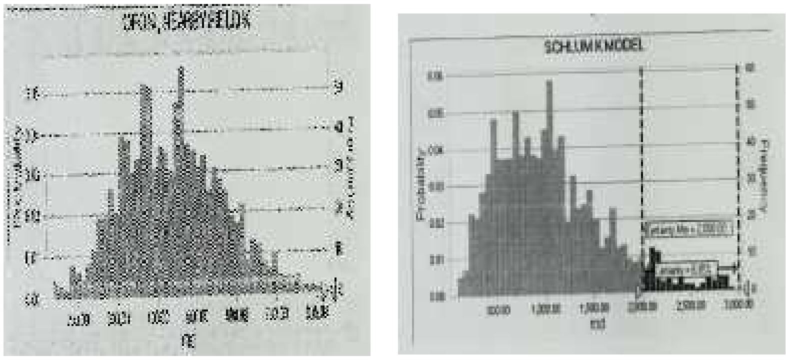

Figure 4: Certainty Level for Ofonmbuk [1] and Schlumberger K model [17] Predictions Within A Permeability Range Of 1800md & 3000md

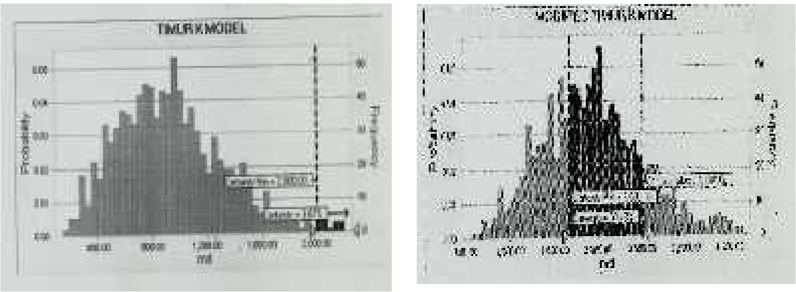

Figure 5: Certainty Level For Timur[2]and Modified Timur K model [17] Predictions Within A Permeability Range Of 1800md & 3000md

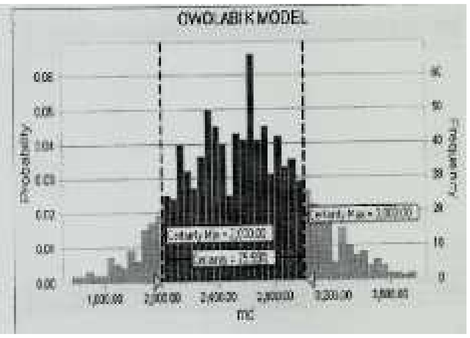

Figure 6: Certainty Level For Owolabi K Predictions Within A Permeability Range Of 1800md & 3000md

From the charts above, one could see that Owolabi's model gave the highest **CERTAINTY LEVEL**. This is in conformity with our previous findings. Thus, our results are valid

21.0 Conclusion

Our analytical investigation of this study gave rise the following conclusions:

- Owolabi's model showed a general distinctive characteristic within most of the permeability flow zones. It performs better in high perm reservoirs
- Tixier and Schlumberger permeability models were seen to predict better in very low flow zones
- There is no existing analytical permeability model that varies only with porosity and water saturation that exactly predicts the reservoir permeabilities. Hence caution should be taken when using them; especially the ones covered in this study.
- Permeabilities were calculated using existing correlations with limited success. Hence new modifications are needed to refine the existing permeability prediction model.

22.0 References

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