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Laboratory and Theoretical Investigations of Petroleum Reservoir Rock Properties

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ABSTRACT

The main objective of this study is to compare the characteristics obtained from the laboratory with the characteristics obtained from well logs and experimental correlations and determine the percentage of error in each method. Core Analysis of reservoir rock is operation of conducting laboratory tests on the core samples to determine their physical and petro physical properties. The Rock sample is first cleaned to be ready for laboratory test then it is used to obtain parameters of rock properties. Well logging is the practice of making a detailed record of the geologic formations penetrated by the well. The log may be either geological logs or geophysical logs in geothermal. Techlog Software is one of the most valuable formation evaluation software's used by geologist and reservoir engineers. It is routinely used to evaluate well and field performance, and reservoir characteristics. After evaluating the results, the crude sample was characterized by using hydraulic unit technique its performing to estimate the units inside the reservoir and establish the correlations to estimate the permeability for each unit. The New Correlations can be used to evaluate the permeability nearby wells. In this study Four wells were selected from different locations in 103A which are A7, A11, A16, and A21 They are used to estimate the petro physical properties of the reservoir by both core analysis and well logging interpretation; the petro physical properties were evaluated like porosity, permeability, and water saturation.

INTRODUCTION

Rock properties are determined by performing laboratory analyses on cores from the reservoir to be evaluated. The cores are removed from the reservoir environment, with subsequent changes in the core bulk volume, pore volume, reservoir fluid saturations, and, sometimes, formation wettability (Tarek, A., 2001)

The effect of these changes on rock properties may range from negligible to substantial, depending on characteristics of the formation and property of interest, and should be evaluated in the testing program. (Tarek, A., 2001)

There are basically two main categories of core analysis tests that are performed on core samples regarding physical properties of reservoir rocks. These are:

Routine core analysis tests (Porosity, Permeability, and Saturation) Special tests (Overburden pressure, Capillary pressure, Relative permeability,Wettability)

Porosity: is a measure of the void spaces in a material. Permeability: a measure of the ability of a material (such as rocks) to transmit fluids. Porosity and permeability are related properties of any rock or loose sediment. Both are related to the number, size, and connections of openings in the rock (Tarek, A., 2001).

The above rock property data are essential for reservoir engineering calculations as they directly affect both the quantity and the distribution of hydrocarbons and, when combined with fluid properties, control the flow of the existing phases (i.e., gas, oil, and water) within the reservoir.

Formation Evaluation (FE) is the process of interpreting a combination of measurements taken inside a wellbore to detect and quantify oil and gas reserves in the rock adjacent to the well. FE data can be gathered with wireline logging instruments or logging-while-drilling tools Study of the physical properties of rocks and the fluids contained within them. Data are organized and interpreted by depth and represented on a graph called a log (a record of information about the formations through which a well has been drilled) (Archie, G. E., 1942).

Techlog is a Schlumberger owned Windows based software platform intended to aggregate all the wellbore information. It allows the user to interpret any log and core data. It addresses the need for a single platform able to support all the wellbore data and interpretation integration workflows, reducing the need for a multitude of highly specialized tools. (Flopetrol, F., 1983).

Objectives

This study aims to achieve this goals

1. Understanding the petro physical properties of reservoir
2. Classify the hydraulic unit of the reservoir.
3. Quick log interpretation by Tech-log Software
4. Calibrate the results obtained from well-logging analysis with core analysis.
5. Compute the porosity and permeability by using different techniques

METHODOLOGY

In this study, I chose one of the most productive Libyan fields and used real data in software to build the geological model

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In this study we have three cores sample well A7-103A (Zoutina O,Company).

Core	Interval
1	9636 – 9692
2	9716 – 9750
3	9885 – 9907

• Collect data and organized it to be appropriate when importing it into the Tech-log software.

• Execute the Hydraulic Unit technique to evaluate the rock types included in the reservoir and create the correlations to estimate the permeability based on this technique.

• Perform quick look interpretation using well logging analysis.

• Estimate the petro physical properties such as porosity, saturation, and permeability by using well logging analysis.

• Calibrate the petro physical properties from both core analysis and well logging analysis.

RESULTS AND DISCUSSION

Table 1: Core Analysis Data of Well A7-103A – Layer 1

Depth	Permeability Horizontal	Porosity	Density	Permeability Vertical
9636	1.2	0.233	2.7	0.01
9640	0.03	0.221	2.7	3.4
9644	0.08	0.264	2.71	2.4
9648	2.51	0.278	2.73	/
9652	6.06	0.302	2.74	/
9656	8.02	0.317	2.75	3.5
9660	1.71	0.261	2.74	/
9664	5.2	0.277	2.72	4.8
9668	5.2	0.277	2.72	4.8
9672	12	0.3	2.77	7.6
9676	8.8	0.3	2.73	11
9680	15	0.302	2.73	7.2
9684	19	0.278	2..74	6.7
9688	13	0.278	2.71	7.2
9692	18.45	3.062	0.340	17.10

Table 2: Core Analysis Data of Well A7-103A – Layer 2

Depth	Permeability Horizontal	Porosity	Density	Permeability Vertical
9716	6.9	0.186	2.71	5.2
9719	24	0.297	2.71	33
9722	3.8	0.325	2.71	17
9725	16	0.277	2.71	0.03
9728	6.7	0.244	2..71	5.5
9731	4.4	0.263	2.72	3.3
9734	9.1	0.248	2..77	0.14
9737	2.27	0.23	2.72	0.11
9740	11	0.255	2.72	0.07
9743	1.9	0.212	2.7	0.02
9746	3.8	0.243	2.71	0.08
9750	2.38	0.268	3.062	2.57

Table 3: Core Analysis Data of Well A7-103A – Layer 3

Depth	Permeability Horizontal	Porosity	Density	Permeability Vertical
9885	5.24	0.305	3.062	5.66
9887	7.87	0.225	3.062	8.49
9889	7.87	0.225	3.085	8.49

9891	7.87	0.225	4.012	8.49
9893	12.54	0.347	3.062	13.53
9895	27.36	0.359	3.062	29.52
9897	10.15	0.340	3.062	10.95
9899	50.16	0.402	3.074	54.12
9901	4.33	0.393	3.074	4.67
9903	12.26	0.380	3.074	0.00
9905	30.78	0.371	3.074	33.21
9907	18.24	0.335	3.074	19.68

Determination of Hydraulic Flow Unit, (HFU)

Hydraulic flow unit concept is used to subdividing the reservoir into different rock types. HFU represents the volume of reservoir rock when its petrophysical and geological properties are different from those of other rock volumes. Each distinct reservoir flow unit has a unique FZI which represents the relationship between Reservoir Quality Index (RQI) which represent geometric distribution of pore space and the normalized porosity (Holditch, S. A., 2000).

RQI=0.0314* √(K/Øe)

Where:

K is the permeability in md.

RQI is Reservoir Quality Index.

Øe is effective porosity in fraction.

Øz=(Øe)/(1-Øe)

Where ϕz is the pore volume to grain volume ratio or normalized porosity.

The FZI is defined by:

FZI=RQI/ϕz

Where FZI is Flow Zone Indicator. Taking the logarithm of both sides yields:

$Log(RQI)=Log(\phi z)+Log(FZI)$

On a log-log plot of RQI versus ϕz all samples that have similar FZI values will lie on a straight line with unit slope. Samples with different FZI values will lie on other parallel lines. The intercept of the unit slope straight line at $\phi z=1$ represents the mean value of FZI. Samples that lie on the same straight line have similar pore throat attributes and constitute a flow unit (Holditch, S. A., 2000).

This figure shows the relations between permeability and porosity for each HFU (Rock Type)

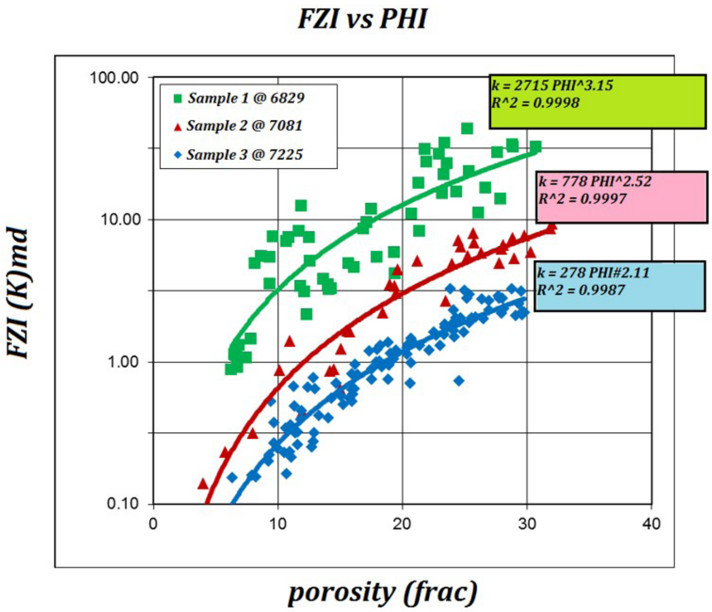

Figure 1: The relations between permeability and porosity for each HFU

Table 4: The relation and gives an idea about the high accuracy of the HFU approach in correlating permeability with porosity

Layer	Correlation Coefficient (R^2)	Relation between K and ϕ	Relation between ϕ and K
HFU#1 (RT#1)	0.9998	K=2715 $\phi^{3.15}$	ϕ=log(k)/ log(2715*3.15)
HFU#2 (RT#2)	0.9997	K=778 $\phi^{2.52}$	ϕ=log(k)/ log(778*2.52)
HFU#3 (RT#3)	0.9987	K=278 $\phi^{2.11}$	ϕ=log(k)/ log(278*2.11)

Quick Look Interpretation

The main target for quick look interpretation is to determine both rock reservoir and non-rock reservoir as well as to select hydrocarbon and water zone. In this section we will show the quick look interpretation for wells A7, A11, A16, and A21, Respectively. [Schlumberger]

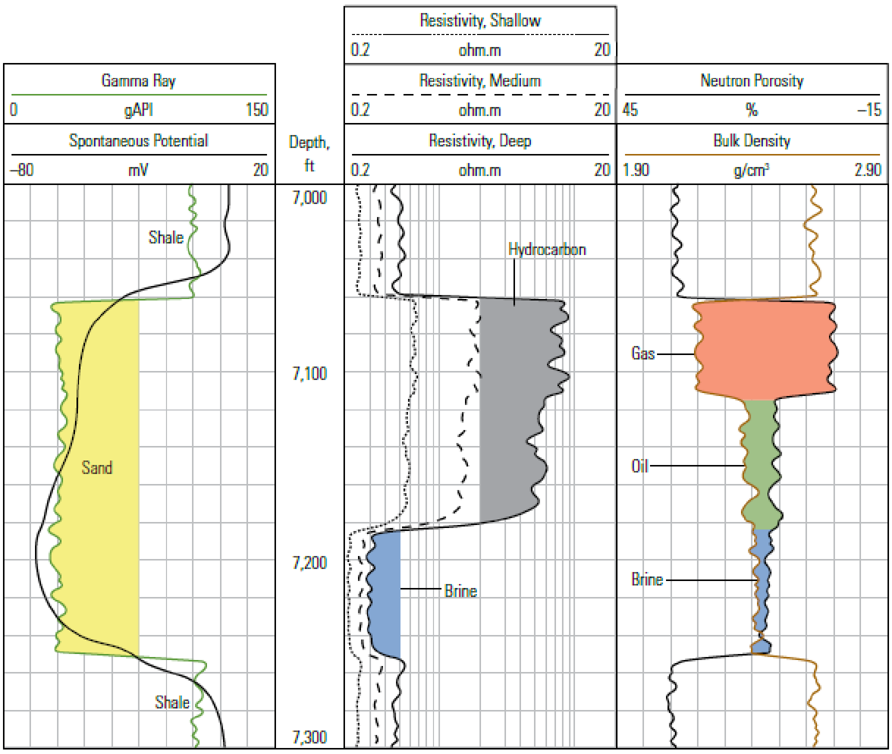

Figure 2: Quick look interpretation from Schlumberger company

Shale Volume

This section presents shale volume content of the formation by using gamma ray interpretation. From gamma ray interpretation the maximum gamma ray and minimum gamma ray can be estimated for wells A7, A11, A16, and A21.

The shale volume is computed by the following formula:

V_{sh}=(GRlog-GRmin)/(GRmax-GRmin)

This formula is used to evaluate the shale volume of the formation according to cutoff for shale, which is about 25% for limestone.[Schlumberger(1984)]

The figures below illustrate the shale volume for each well of 103A as well.

Porosity Logs

Density log, Neutron log and Sonic log, these logs also known as porosity logs. From these logs' porosity can be estimated. Neutron log gauges the porosity directly based on the Hydrogen Index (HI), but the density log measures the bulk density which is used to compute the porosity. The sonic log calculates the wave travel per time that used to estimate the porosity.

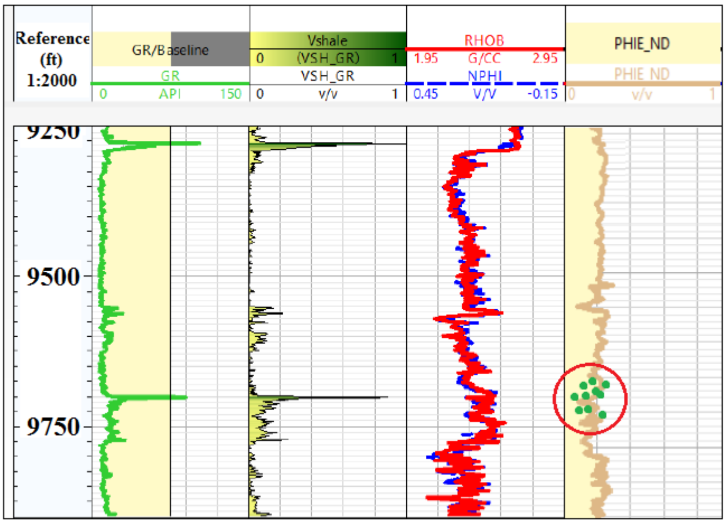

Figure 3: Porosity Estimation of well A7-103A

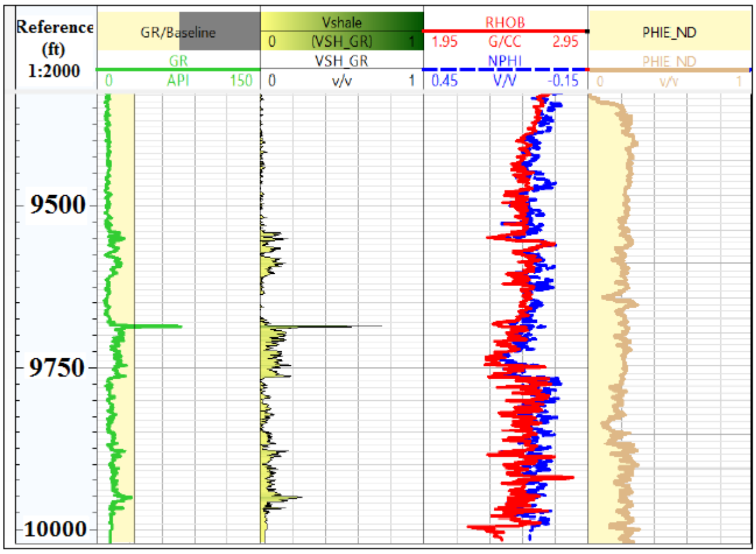

Figure 4: Porosity Estimation of well A11-103A

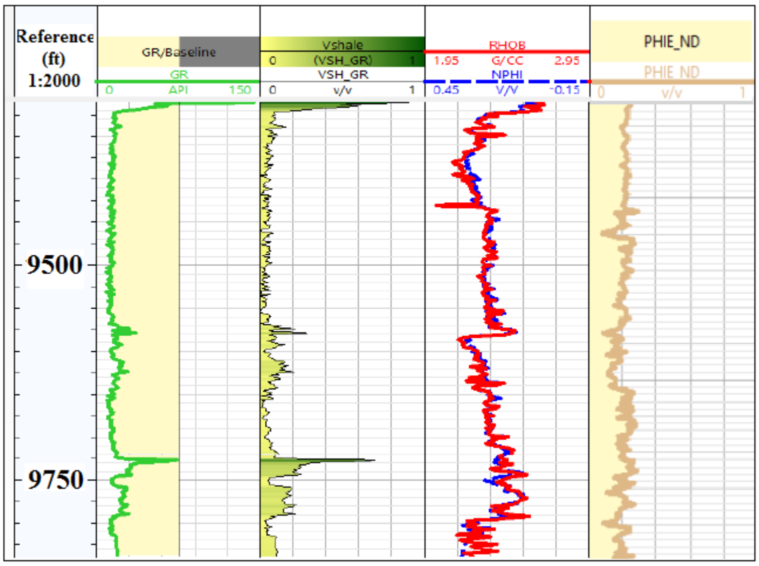

Figure 5: Porosity Estimation of well A16-103A

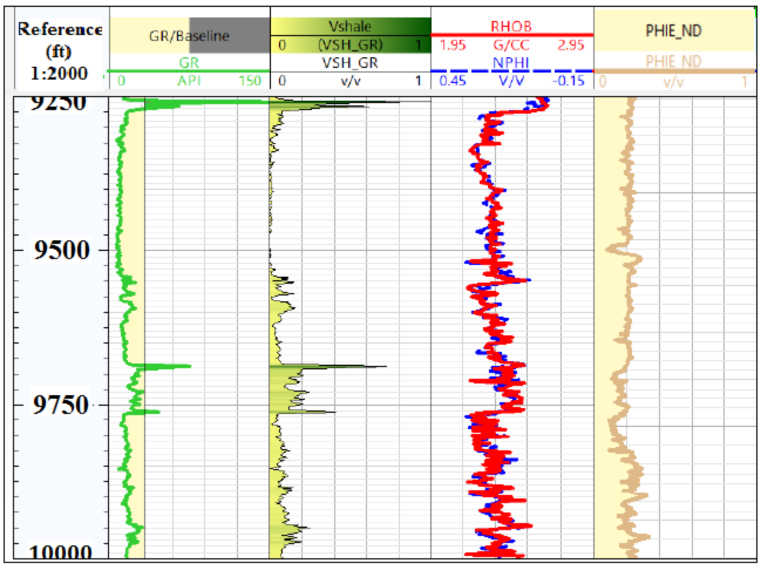

Figure 6: Porosity Estimation of well A21-103A

Generally, density and neutron logs plotted in with each other in the well, in order to indicate the gas zone and oil zone. When porosity is computed, the effect of shale on porosity logging responses must be evaluated (Schlumberger, 1984).
The formula used to compute the porosity from density log is listed below:
$Ø_D$=(Pmatrix-Plog)/(Pmax-Pfluid)
If the amounts of gas and shale in the formation under evaluation have approximately the same effect on both the Density and Neutron measurements, the following set of equations can be used to calculate a value of effective porosity:
$Øt=\sqrt{((Ø^2_N+Ø^2_D)/2)}$
$Øe=Øt(1+V_{sh})$
From the figures below, it indicates the acceptable results of porosity from well logging comparing with cores. So, it means can be used either the cores or well logging to determine the porosity for this area (Schlumberger, 2000).

Electrical Logs

The resistivity of formation rock being evaluated is a key parameter in determining hydrocarbon saturation. Electricity can pass through a formation only because of the conductive water is present.
Subsurface formations generally have finite measurable resistivity because of the water in the rock pore space bounded by grain size or capillary pressure or absorbed in the native interstitial clay.
Resistivity logs is divided substances into two general categories, conductors or insulators.

- Conductors are substances that pass electrical current e.g. water, shales, mud.
- Insulators are substances that do not allow electrical current to flow (because of their electron structure and distribution) e.g. hydrocarbons, or rock matrix.

The measures resistivity of a formation depends on the:

- Resistivity of the formation water (RW).
- Amount of water present. (Ø and SW).
- Pore structure geometry (F).

Formation Water Resistivity a function of several factors.

Water Salinity

As salinity increases, more ions are available to conduct electricity so Rw (water resistivity) decreases.

Water Temperature

As water temperature is raised, ionic mobility increases and resistivity decreases.
To calculate formation water resistivity, it needs a salinity of NaCl and average reservoir temperature. Equations below are used to find the resistivity's at a given temperature (Calhoun, J. R., 1976).
$R_{W75F}=(1/(2.27\times10^{(-4)}\ C))+0.0123$
$R_{WX}=R_{W75F}\ ((75+6.77)/(Tx\times6.77))$
A few have worked on the effect of pore size and distribution in the evaluation of water saturation in these kind of rocks (Alger *et al.*, 1989; Obeida *et al.*, 2005; Lucia, 2007) perhaps the most significant contribution is the equation by Lucia.
$SW=a\times H^b\times Ø^c$
In this equation, H is the reservoir height (vertical thickness of the reservoir zone), a, b, and c are constant coefficients which are the functions of rock type and grain size.

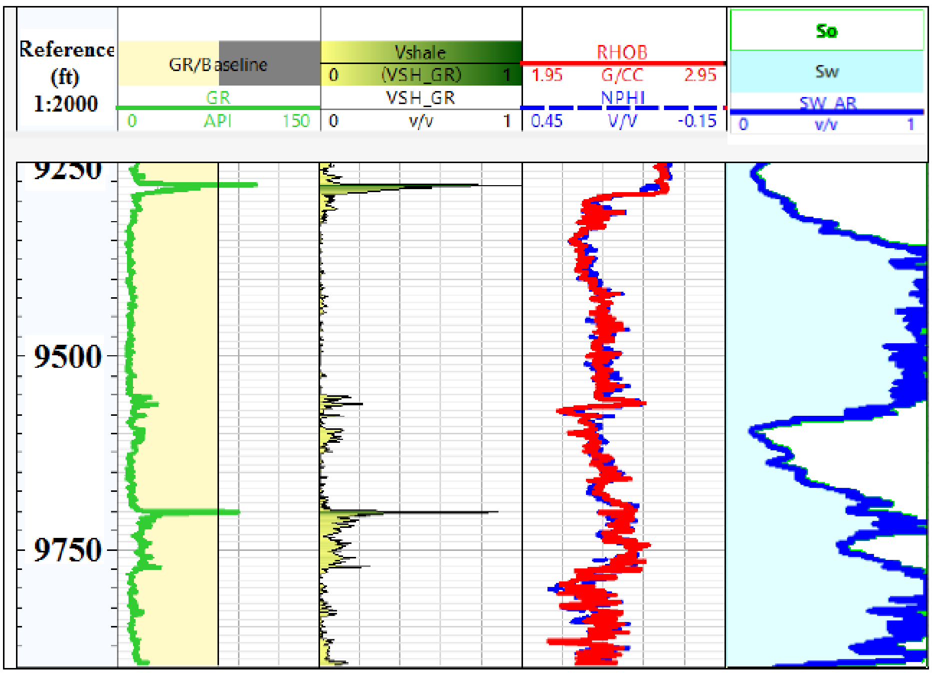

Figure 7: Water saturation of well A7-103A

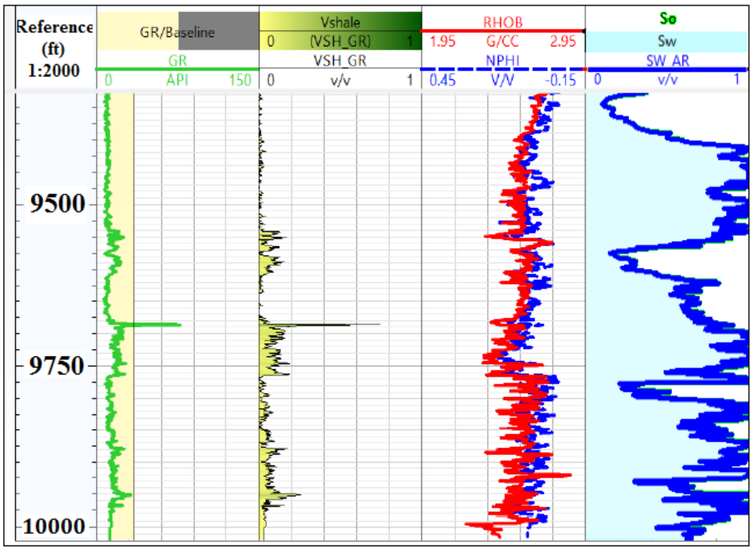

Figure 8: Water saturation of well A11-103A

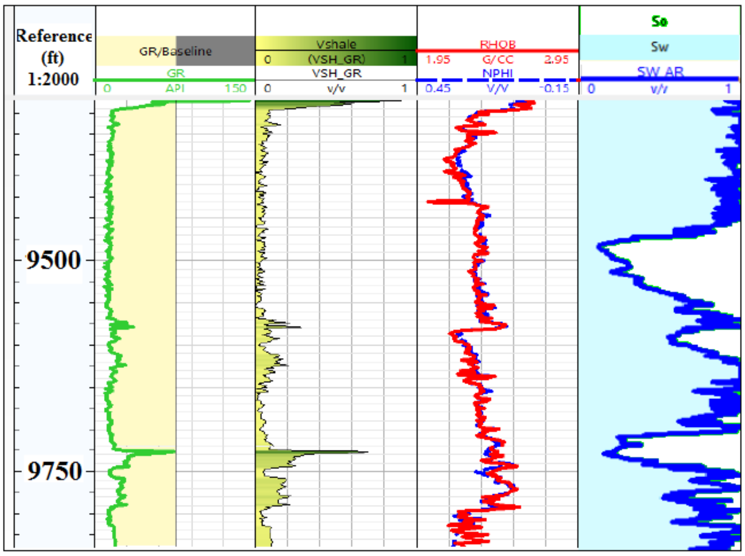

Figure 9: Water saturation of well A16-103A

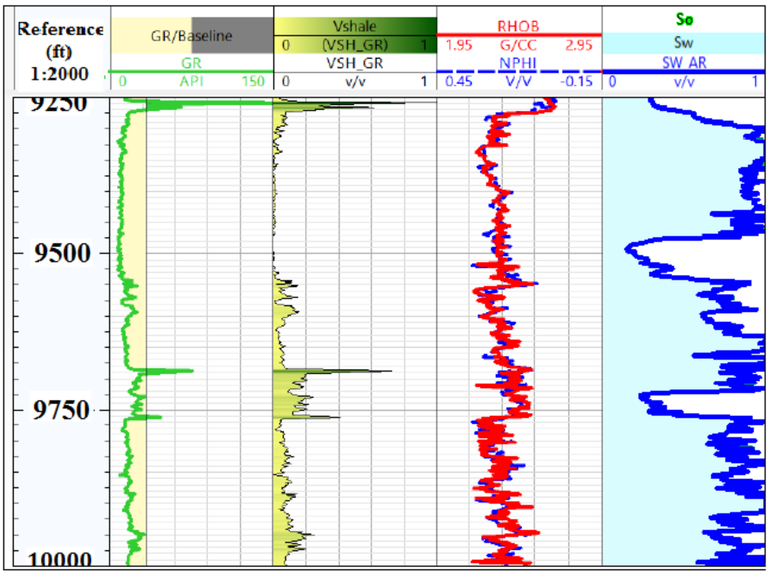

Figure 10: Water saturation of well A21-103A

Permeability Estimation

The permeability was computed by several equations (SERRA, 1984),

Morris and Biggs Equation

$K=((CØ^3)/(S^2_{wi}))$

Where:

k = Permeability (md)

Ø = Porosity (fraction)

Swi = Irreducible water saturation (fraction)

C = Constant; oil=250; gas=80

Timur Equation

$K=((0.136Ø^4)/(S^2_{wi}))$

Where:

k = Permeability (md)

Ø = Porosity (fraction)

Swi = Irreducible water saturation (fraction)

Wylie and Rose Equation

$K=((100Ø^{2.25})/(S_{wi}))^2$

Where:

k = Permeability (md)

Ø = Porosity (fraction)

Swi = Irreducible water saturation (fraction)

Coates-Dumanoir Equation

$K=(100Ø^2\ ((1-S_{wi})/(S_{wi}))^2$

Where:

k = Permeability (md)

Ø = Porosity (fraction)

Swi = Irreducible water saturation (fraction)

In addition to that, the permeability correlations which have been obtained from the hydraulic unit application technique were used to estimate permeability, the correlations are:

$K=278.28\phi^{3.7073}$ And $K=1849.8\phi^{3.7558}$

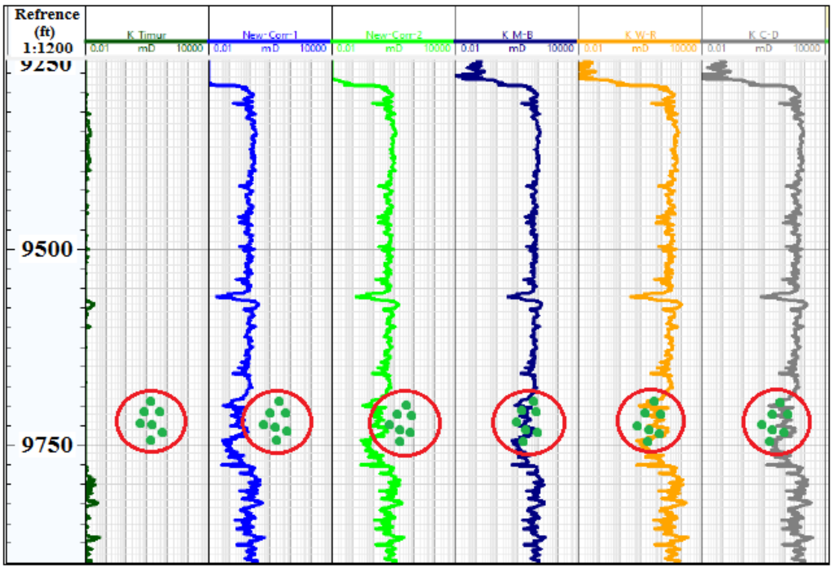

Figure 11: Estimated Permeability of Well A7-103A

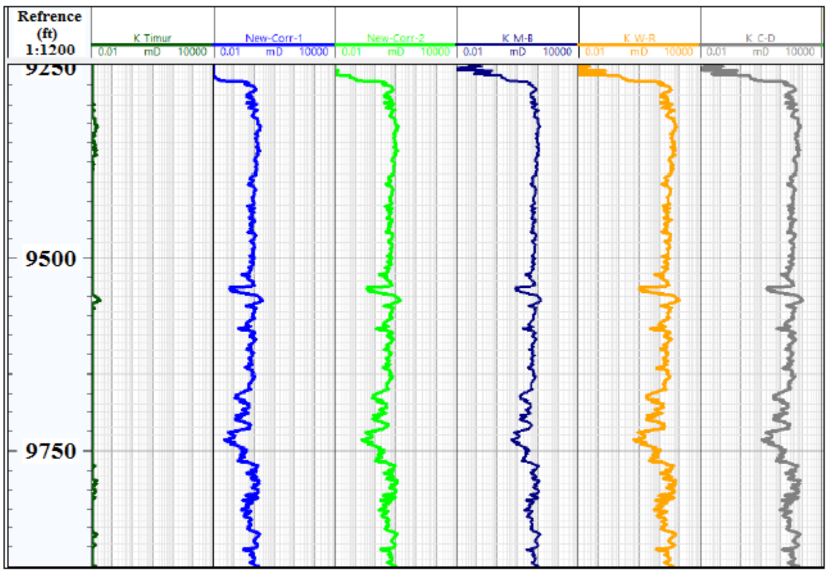

Figure 12: Estimated Permeability of Well A11-103A

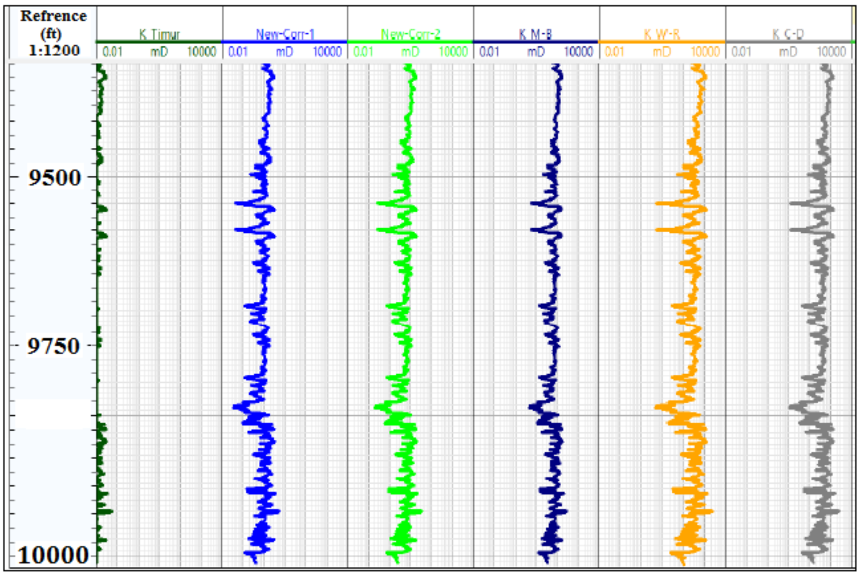

Figure 13: Estimated Permeability of Well A16-103A

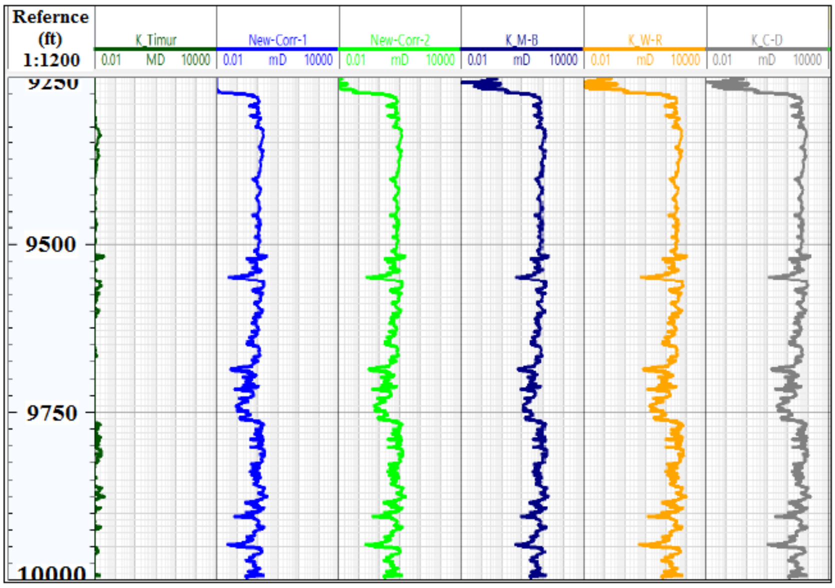

Figure 14: Estimated Permeability of Well A21-103

Summary of Results

Table 5: Porosity

Porosity (%)	Well A7	Well A11	Well A16	Well A21
Laboratory	17.55	18.86	16.85	16.81
HFU	26	29	25	25
Tech-log Software	18.4	20.1	17.8	15.4

Table 6: Permeability

Permeability (md)	Well A7	Well A11	Well A16	Well A21
Laboratory	11.8	12.4	9.3	10.7
HFU	11.3	14.1	9.9	9.8
Tech-log Software	6.82	3.52	2.3	2.3

Table 7: Saturation

Saturation (%)	Well A7	Well A11	Well A16	Well A21
Laboratory	7.32	8.9	5.76	13.13
Lucia equation	12.5	14.1	9.2	17.4
Tech-log Software	35	30	37	32

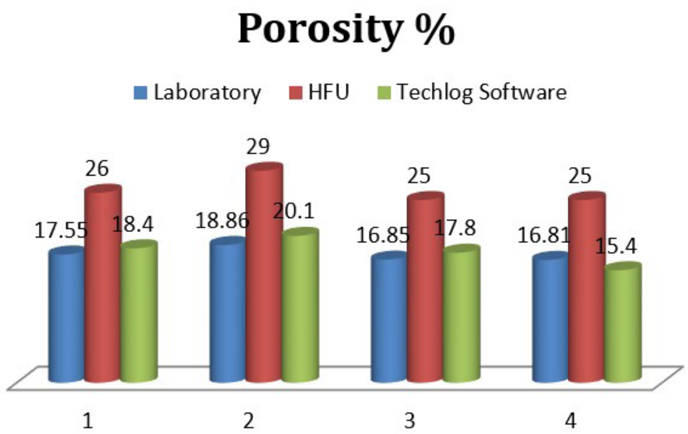

Figure 15: Porosity

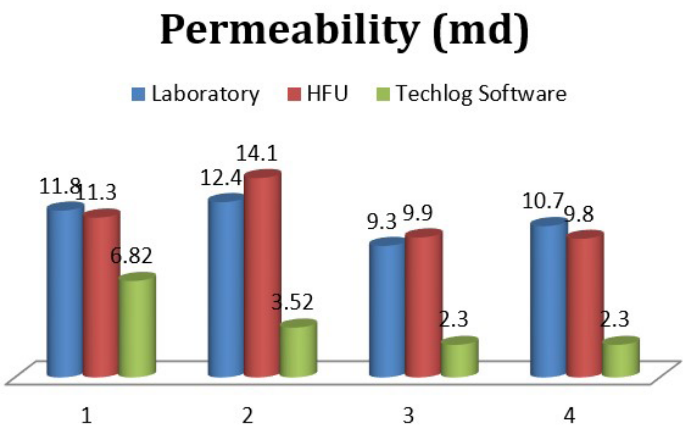

Figure 16: Permeability

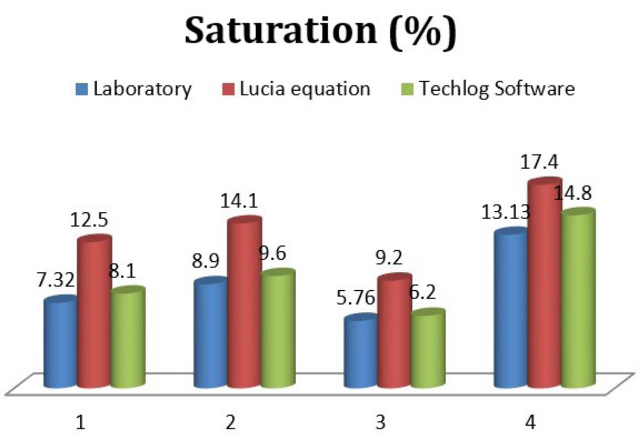

Figure 17: Saturation

CONCLUSIONS

Based on the results of this study, the following conclusions are obtained:

• The porosity obtained from Tech-log Software gave good results with a lower error rate than the experimental correlation of the hydraulic unit technology.

• The permeability obtained from the experimental correlation of the hydraulic unit technology gave good results with a lower error rate than Tech-log Software.

• Water saturation obtained from Tech-log Software

(Archie equation) gave good results with a lower percentage of error than the Lucia equation for saturation.

• The new correlation can be used to estimate the permeability in the area around selected wells that we were working on it in this study.

RECOMMENDATIONS

The main recommendations we can get from this study are:

• Using Tech-Log Software to calculate porosity in nearby wells in field 103A instead of the high cost of core analysis.

• Using the experimental correlation of the hydraulic unit technique in calculating the permeability instead of the high cost of core analysis

• Use Archie's equation instead of Lucia's to calculate saturation Verify that the properties are correct before entering them into Tech-log Software

• The study should be developed by using more samples to reduce the error rate of the results

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