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Influence of Simulated Overburden Pressure on Core Permeability and Porosity in the Niger Delta

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ABSTRACT
This study investigates the influence of simulated overburden pressure on core porosity and permeability of sandstone rocks in the Niger Delta**.** The examination was carried out using non-linear regressions to assess suitability of both models (Power model and Exponential model). The R2 parameter was used to assess the goodness of non-linear regression (coefficient of determination). The power law influences the simulated overburden pressure as compared to the exponential model as its values are relatively larger in comparison to that of the exponential model.Fifteen core samples was used for analyses, P1, P3, P5, P7, P9, P11, P13, P15, P17, P19, P21, P23, P25, P27 and P29.An increase in pressure shows a greater decrease in permeability for core samples, P1, P3, P9, P15, P27 and P29. This could happen due to the disintegration of angular shape pores. Furthermore, simulated overburden pressure has greater influence on pore throat (fluid pathway) in correlation to pore size. Hence the possibility of influencing few of the connected fluid pathways.The outcome of core samples P11, P17, P19, P21, P23 and P24 had the least permeability values, compared to other core samples. A constricted flow path is expected. Increase in simulated overburden pressure, the initial pressures of P1, P3, P5, P7, P9, P11, P13, P15, P17, P19, P21, P23, P25, P27 and P29 samples are reduced respectively. Hence, simulated overburden pressure has less effect on porosity in contrast to permeability under similar pressure conditions.

Keywords: Overburden Pressure, Core, Porosity, Permeability, Niger Delta, Non-Linear Regression, Power Model and Exponential Model

I. INTRODUCTION

It is has proven that both porosity ϕ (Biot, 1957;Detourney andCheng, 1993; Geertsma, 1957; Marek, 1971; Carroll, 1980) and permeability k (Sigal, 2002; Ostension, 1987; Zhu et al., 2008) change with pressure. This can be explained by the following equation.

$$\frac{\phi}{\phi}(A) = \frac{k}{ko}$$

Where ϕ and k represent the porosity and permeability at reference state, and exponent (A) is a parameter that varies with rock type and sometimes the sequence and record of pressure. And also the influence of pressure is important during reservoir engineering calculations. In various oil fields the individual manner of the reservoir has been assign to the influence of pressure on rock permeability and porosity, understanding the influence of simulated overburden pressure on core permeability and porosity of rocks, critical for studying the fluid passage in the reservoirs. The character of the reservoirs will be altered when the subsurface pressure is distorted. As a result, the reservoir's porosity, permeability, and other major physical characteristics changes (Wong et al. 2007). Any alteration of simulated overburden pressure of the formation influences its porosity and permeability, which may influence the volume and also the generation of the reservoir (da Costa et al 2021).

There are many different types of pores in real porous rock, and not all of them are good at transporting fluid. When you look at porosity in terms of net connections, you can classify it as "effective" or "non-effective." Pore throats are thought to be more pressure-receptive in "effective" porosity than in "non-effective" porosity, which has no effect on permeability (pore bodies). Porosity that is "non-effective," according to Bernabe and Evans 2003 is "pore space with a flow velocity significantly slower than the mean flow velocity through an entire porous medium (less than 1%), but still considered to be a part of the connected pores." They were the ones who coined the phrase. Changes in these formations' porosity and permeability can affect their capacity to store and make or inject fluids. Many experiments in the laboratory have been carried out over the years to discover how pressure alters the porosity and permeability of rocks and fault gouges, which are unsolidified rocks with small grains (Brace et al. 1968; Debschutz et al. 1989; Gaus et al. 2019; Hangx et al. 2011; Salimidelshad et al. 2019; Tanikawa and Shimamoto 2009; Zoback and Byerlee 1975). Pressure is the most important factor in determining how much porosity and permeability there is, according to all of the tests. Consider the pressure of the overburden when determining the porosity and permeability of rocks.

Studies have shown that the pressure history of a sedimentary basin and the loading conditions that were in place at the time of testing affect rock porosity and permeability values (Civan 2017; Fink et al. 2017b; Hangx et al. 2010; Kwon et al. 2004 a&b; Moghaddam and Foroozesh 2017). Depending on the overburden pressure, two different types of models can be used to predict changes in permeability and porosity. A power law or exponential equation can be used to describe these. The nature and composition of the reservoirs rock can be altered once the subsurface pressure is disrupted, the outcome, the porosity, permeability and further major physical attributes of the reservoir alter in return. Therefore, understanding the influence of simulated overburden pressure on core permeability and porosity of the formations in the Niger Delta is critical for evaluating the flow of oil and gas in the reservoir. This will be achieved by analyzing rock core samples from Niger Delta area, to obtain different porosity and permeability changes, when the reservoir insitu-pressure is altered.

II. BACKGROUND TO THE STUDY

Fundamental of Reservoir Rock Properties and Core Analysis

The characteristics of the reservoir fluids and the permeable medium that contains them - the subsurface rock - determine the reservoir type. Seismic data, core descriptions, wire line logs, well tests, fluid analyses, and production history typically describe these properties. A variety of reservoir rock properties are examined using core samples. Why guess when you can physically measure of the reservoir rock's features for reliable reservoir engineering calculation? Laboratory core analyses help interpret reservoirs. Only core samples of the reservoir rock are visible for study and analysis of vital flow processes. Core analysis is basically used for:

- Reservoir geological model
- Computation of total hydrocarbon in place (total asset)
- Determination of productivity index

$$PI = \frac{K}{\mu_o.B_o}.\frac{h_n}{h_t}$$

- Determination of recovery (bankable asset).

The information provided after laboratory analyses of the core, is then used by modelers to enhance the capability of the reservoir in question, to decrease uncertainty in their reservoir models and, in many cases, addressing specific problem areas such as formation damage.

Successful core analysis requires coring, sample preservation, and sample screening.

Pore Scale Control

Pore and pore throat sizes control capillary pressure and permeability. These relative sizes are strongly influenced by pore filling cements, clays and other secondary minerals.

Core Description

A detailed description of lithology, bed thickness, texture, sedimentary structures, including fractures, biological features, and depositional environment. Data on porosity, permeability, and grain density can also be plotted on the log. Sample points for petrographic or petrophysical analysis may also be marked. The whole log can be plotted with wire line traces.

The core description describes the rock type, deposition and diagenesis environments, dip angle and direction, and fractures. Combine this with other nearby well core descriptions, seismic profiles, and regional tectonic data to create a 3-dimensional geological model of the reservoir. This is the basis of the reservoir model.

Uses of Core Analysis

Laboratory core analysis data are used to help plan the evaluation and development of oil and gas supplies.

To account for uncertainty in core analysis data, Bouchard and Fox published a method.

Laboratory core analysis measurement uncertainty can be quantified. However, uncertainties caused by non-reservoir rock and/or fluids, non-reservoir stresses, and non-reservoir wettability samples cannot be quantified.

Purpose for Coring

Drilling core serves one purpose. Supplying details of; geological studies, routine and special core analyses, rock mechanics and formation damage.
The only visible part of the reservoir rock for studying vital flow processes is the core specimen.

Core Analyses at Well Site

The information provided by description and analysis of cores is typically used by geologists, petrophysicists and reservoir engineers to improve the understanding of the reservoir in question, to reduce uncertainty in the reservoir models.

The core approach at the well site and to the laboratory is critical. If not done properly, the core may be damaged, invalidating many laboratory tests. As soon as the core reaches the surface, it must be kept as intact as possible.

Porosity

Tarek (2006) defines porosity of a rock as a proportion of rocks ability to store of hold fluids. This storage capacity is regularly alluded to as pore volume. Rocks with higher tendencies to store fluids are often referred to as porous rocks. Porous rocks are essential requirement of hydrocarbon reservoirs.
Normally, porosity can be written as:

$$\text{Porosity} = \frac{\text{PoreVolume}}{\text{BulkVolume}}$$

Porosity is often represented symbolically as Ø.
The above equation also matches Yang et al. (2019) definition of porosity as the ratio of pore or void volume to naturally visible or mass volume.

Absolute Porosity

The ratio of pore space volume to total rock volume in a reservoir rock. Pore interconnectivity is critical for rock to liquid capacity. An impressive absolute porosity stone lacks connectivity to liquid due to lack of pore interconnectivity.

Effective Porosity

This is the mass volume divided by the void spaces. The effective porosity is the only place where liquids can be delivered from wells. Porosity in granular materials, like sandstone, can progress to total porosity due to pore space availability and connectivity. Also, effective and absolute porosity can vary greatly in shale and other highly solidified or vugular rocks (calcium is a good example).

PERMEABILITY

Permeability is the ability of the reservoir rock to conduct and transmit fluid. It is an important factor in all reservoir studies. The permeability of subsurface rock, denoted by the symbol k, is critical to comprehend.
It also refers to how easily liquids, gases, or chemicals pass through a material.
To test a material's permeability, apply a head and measure the depth of penetration or the volume of liquid or gas passing through the sample. Pore throat constrains it because it relies on interconnected pores.
1 Darcy = $9.8*10^{-13}m^2$
Basically, there are three types of permeability, they include:

Absolute Permeability

Is the permeability estimated at 100% immersion of a solitary/single stage fluid? In any case, in oil repositories, the oil is normally soaked with at least two liquids, which incorporate water, oil and gas.

Relative Permeability

Is considered as the proportion of the effective permeability of a liquid at a specific saturation to the total permeability of the liquid at 100% saturations.

Effective Permeability

It is the capacity of a rock to conduct a specific fluid when its saturation is less than 100% in the rock pores.

III. MATERIALS AND METHODS

The core specimen was retrieved from sandstone formation in the Niger Delta from X wells. The samples were bored with 2 inches boring tool and dried for fewdays at 80ºc to reach a steady mass. With the point of, giving an account of the influence of simulated overburden pressure, the specimen was cored at 90 degrees to the bedding description of the core specimen.

Laboratory Analysis

The steps undertaken are outlined below:
- The sample was retrieved from the core plug which had been cut from the full core recovered from the wall.
- The core specimen is put in a specimen holder.
- Applied precise simulated overburden pressure dependent on the supply pressure.

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- Read off simulated overburden pressure of porosity data from the hardware determined dependent on Boyle's law.
- Read off simulated overburden pressure of permeability outcome from the hardware determined dependenton unsteady state method (Pazos et al. 2009).
- Modifying simulated overburden pressure and redo the steps over again.

Experimental Setup

The steps undertaken are outlined below:

- Cup holder, which houses the core
- Pressure transmitter which controls and monitor pressure.
- An apparatus which measures porosity and permeability values.
- A pressure generating system.
- Different gas bottles with various volume limits.

Figure 1: Diagram of the mechanism of equipment

Figure 1 depicts the experiment's set-up schematically. Core holder, confining loading system, gas tank reservoir with different volume capacities, and a high accuracy pressure transducer (0.01 psi resolution) are all part of the setup. The system also includes an automatic porosity and permeability measurement system. Biaxial core holders allow us to apply equal axial and radial confining pressures to core samples up to 10,000 psi with hydrostatic core holders. A movable piston applies axial load to the core, while a Viton sleeve applies radial pressure to the core.

Mechanism of the Equipment

The cup holder helps to apply simulated overburden pressures on the core specimen up to 10,000 psi. Pressing factor applied deeply to the core specimen through a mechanism. The applied pressure reaches the core through a vitron sleeve. The equipment computes permeability to the scale of 0.006 to 1300mD utilizing temperamental state strategy. Furthermore, the equipment computes porosities in a scope of 0 – 79.99% with an accuracy of 0.01%. The fluid used for this experiment to determine porosity and permeability data's is Helium gas. The temperature is kept constant (25˚) get rid of gas rising due to the outcome of rise in temperature.

Evaluation of Permeability and Porosity

Two types of equation (model) were used to assess the behaviour and tendencies of permeability and porosity outcome as a result of simulated overburden pressure of the core sample. The equation for the Power law model is given below;

$$Y = Y_0\left(\frac{p_e}{p_o}\right)^{-a}$$

Y represents Porosity, or Permeability,
Y_0 represents initial Porosity, or Permeability,
P_0 represent initial Pressure,
$P_e$represents effective Pressure,
q represent material constant.
Note that the values of q determine the amount of simulated overburden pressure of the samples characteristics.

IV. RESULTS AND DISCUSSION

Results

Model to Illustrate Pressure and Permeability Values

The simulated overburden pressure valuesof permeability can be explained by a power law and or an exponential equation. This paper, an examination was carried out using non-linear regression to assess the suitability of both models. The goodness of non-linear regression was evaluated by using R^2 parameter (the coefficient of determination) which is illustrated in table 1.

Table 1 Estimation of various data specimen using power law and exponential equations (model)

Sample ID	Power law equation		Exponential equation	
	Applied Pressure		Applied Pressure	
	a	R^2	ϒ(Psi^{-1})	R^2
P1	0.3836	0.998	3.72×10^{-5}	0.955
P3	0.3067	0.994	2.19×10^{-5}	0.970
P5	0.5197	0.998	3.72×10^{-5}	0.924
P7	0.1496	0.992	1.07×10^{-5}	0.975
P9	0.2398	0.983	1.71×10^{-5}	0.867
P11	0.0860	0.999	6.16×10^{-6}	0.949
P13	0.1594	0.999	1.14×10^{-5}	0.933
P15	0.1801	0.999	1.29×10^{-5}	0.926
P17	0.0380	0.981	2.72×10^{-6}	0.861
P19	0.0995	0.996	7.13×10^{-6}	0.907
P21	0.1375	0.991	9.85×10^{-6}	0.977
P23	0.1037	0.936	7.43×10^{-6}	0.999
P25	0.1323	0.965	9.47×10^{-6}	0.996
P27	0.2352	0.989	1.68×10^{-5}	0.980
P29	0.1886	0.996	1.35×10^{-5}	0.966

From the table above, the power lawmodel analyse the simulated overburden pressure of permeability more than exponential form in that, simulated overburden pressure influences the power law model more compared to the exponential model, as its values are relatively larger compare to that of the exponential model.Also, it has prescribed R^2 closeto one. In conclusion, the behaviour of the core specimen can be analysed using a power law model.

Discussion

Influence of Pressure on Permeability

To analyse the influence of simulated overburden pressure on core permeability for sandstone rock in the Niger Delta, the permeability estimate are derived by dividing the outcome of permeability at any applied pressure to the initial permeability at 500psi. Reservoir rock samples brought to the surface expand because of removal of overburden pressure. This expansion is evidently not uniform, probably because of grain orientation and bedding effects. The result of this nonuniform expansion is a uniform change in permeability along the mutually perpendicular axes.Table 1 illustrate the various permeability value ranges between 0.50287 to 1 milli Darcy, when the simulated overburden pressure rises, the permeability obviously lessen.From the chart below, as simulated overburden pressure increases, permeability decreases, especially during the early stages of pressure rise, for core specimen P1, P3, P5, P9, P15, P27, and P29. This could happen due to the disintegration of angular shape pores (Tekluet al.2018).

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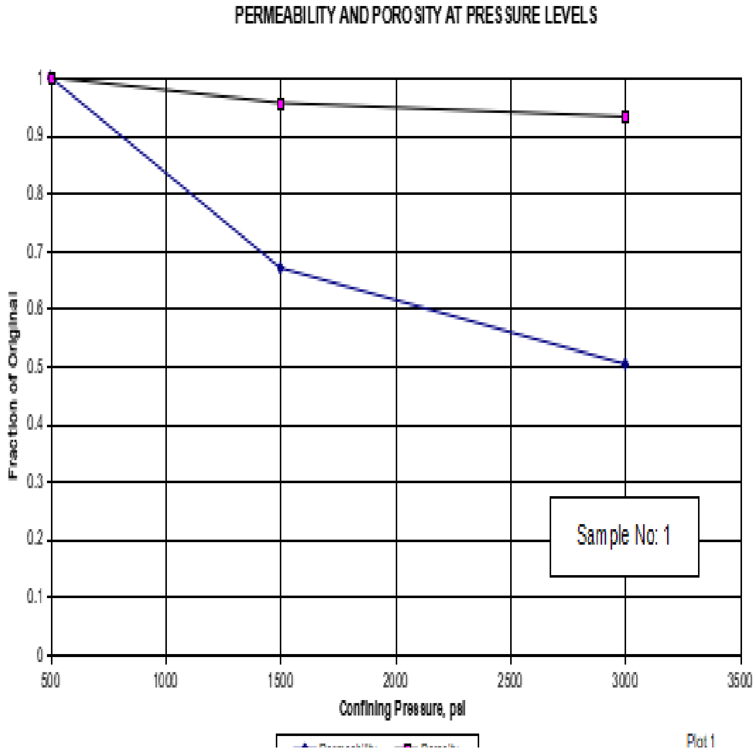

Figure 2: Graph of sample P1 with greater permeability reduction

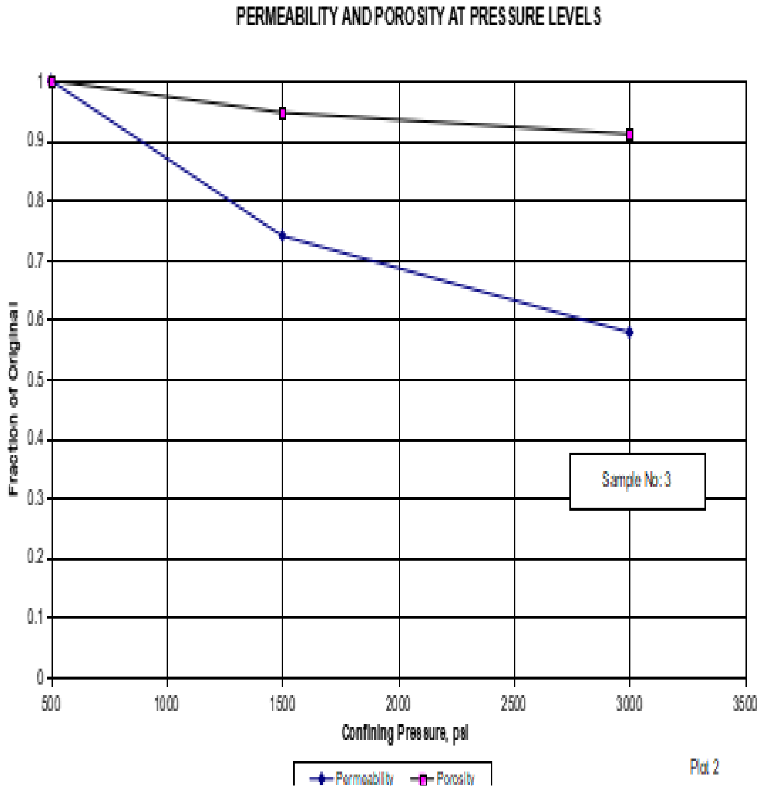

Figure 3: Graph of sample P3 with greater permeability reduction

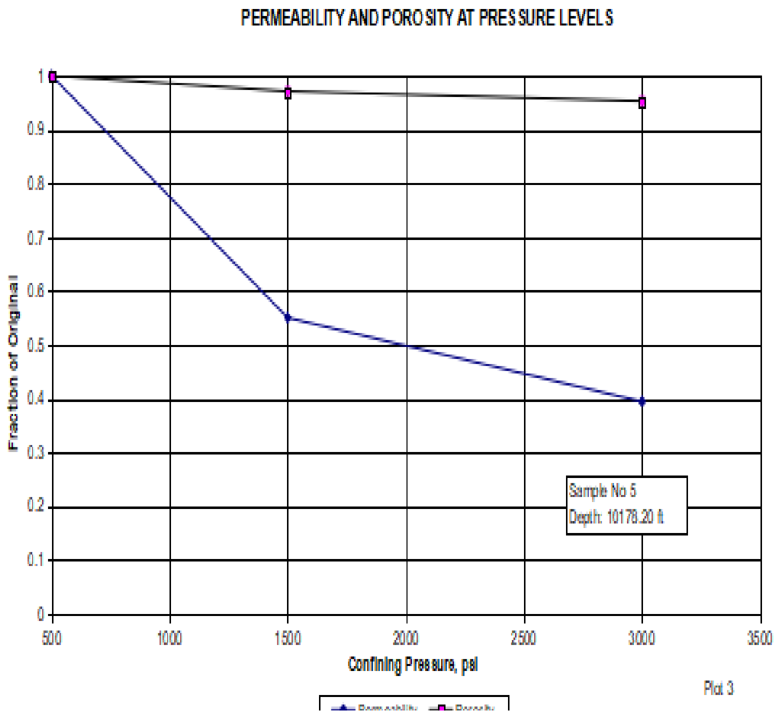

Figure 4: Graph of sample P5 with greater permeability reduction

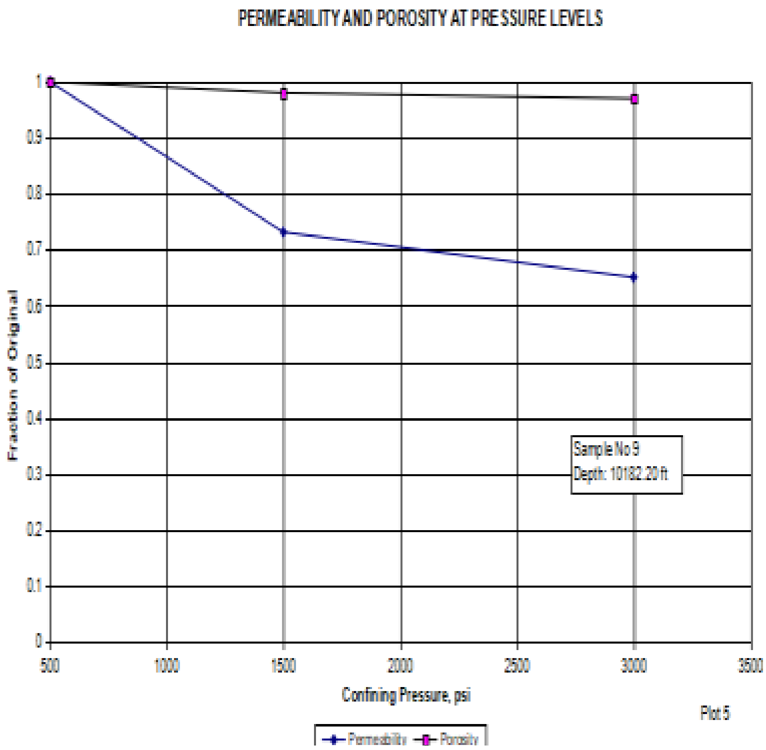

Figure 5 Diagram of sample P9 with greater permeability reduction

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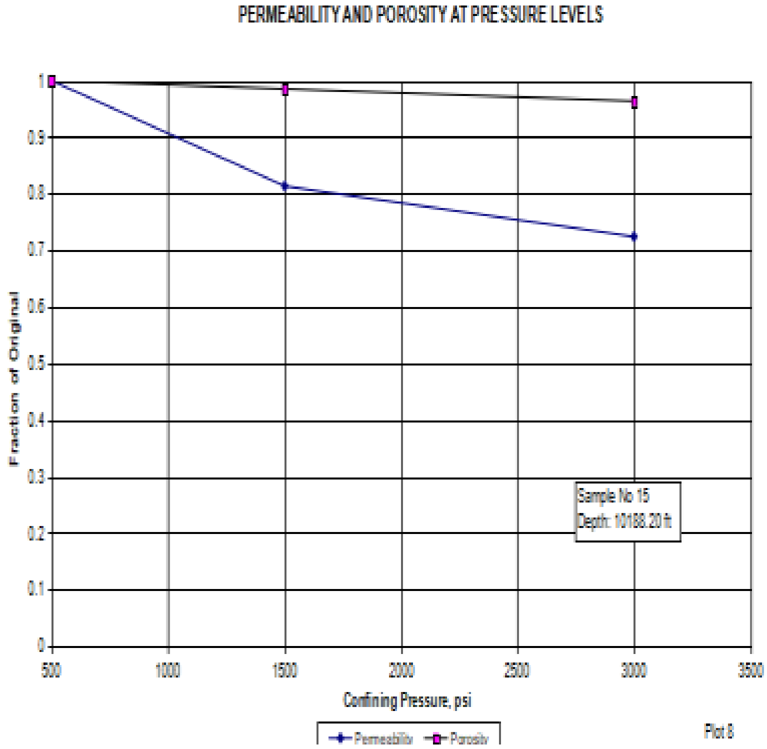

Figure 6 Diagram of sample P15 with greater permeability reduction

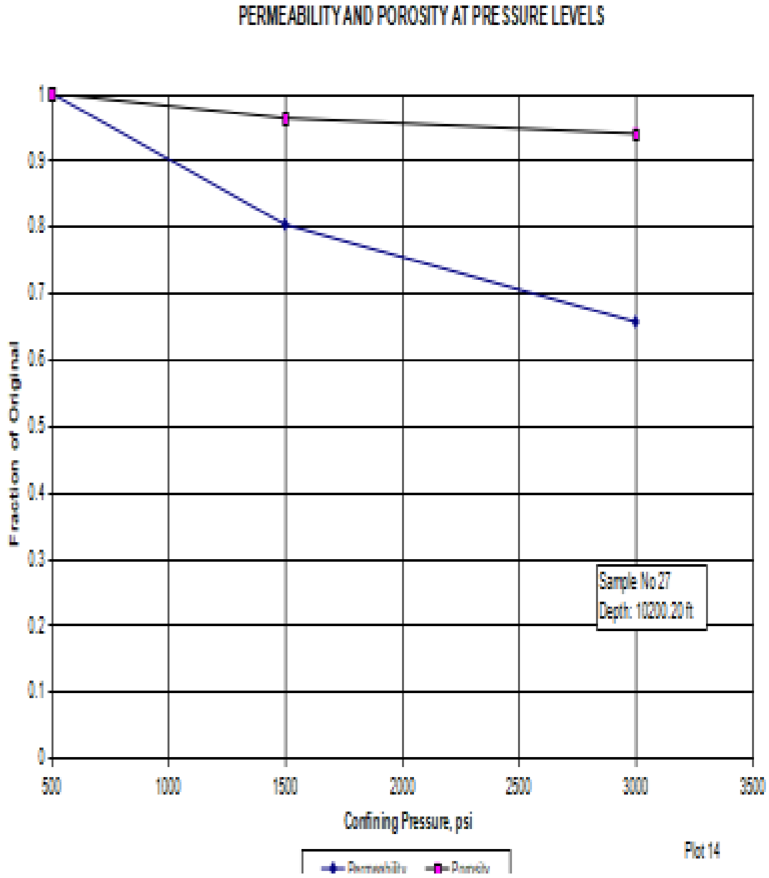

Figure 7 Diagram of sample P27 with greater permeability reduction

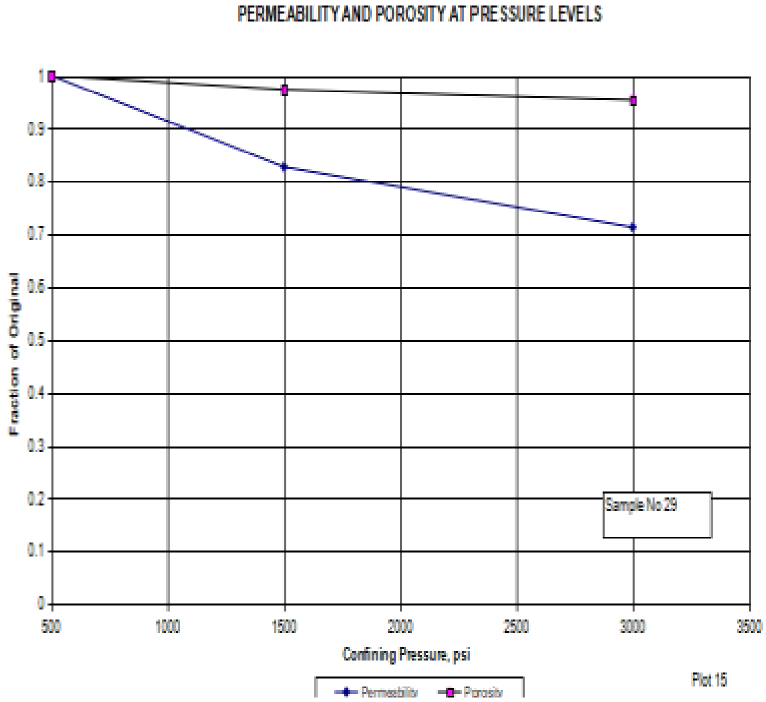

Figure 8 Graph of sample P29 with greater permeability reduction

Again, the reservoir rocks are heterogeneous having complex variation in nano and micro pores, which could lead to cracks as the pressure increases. This can alter the flow of fluid.On account of abrupt permeability decrease (core specimen P1, P3, P5, P15, P27 and P29), it appears that nano and micro cracks within the core specimen was pliable as compare to other core specimen. As such, as pressing factor is profoundly applied to the core specimen, it will definitely influence the flow of fluid.Furthermore, simulated overburden pressure has greater influence on pore throat (fluid pathway) in correlation to pore size. Hence, the possibility of ruining few of the connected fluid pathways, thus, increase in simulated overburden pressure.The outcome of the core specimen (P11, P17, P19, P21, P23 and P25) is discussed separately here as it looks to have a distinct trend. Figure 2 to Figure 8 proves that, (P11, P17, P19, P21, and P25) had the least permeability values compare to the other core specimen; a constricted flow path way is expected. The above reasons can influence permeability reduction.

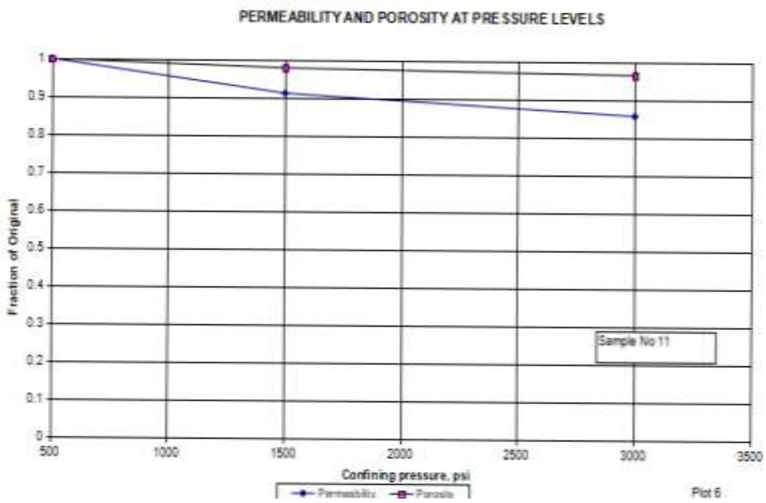

Figure 9 Graph of sample P11 smallest permeability reduction

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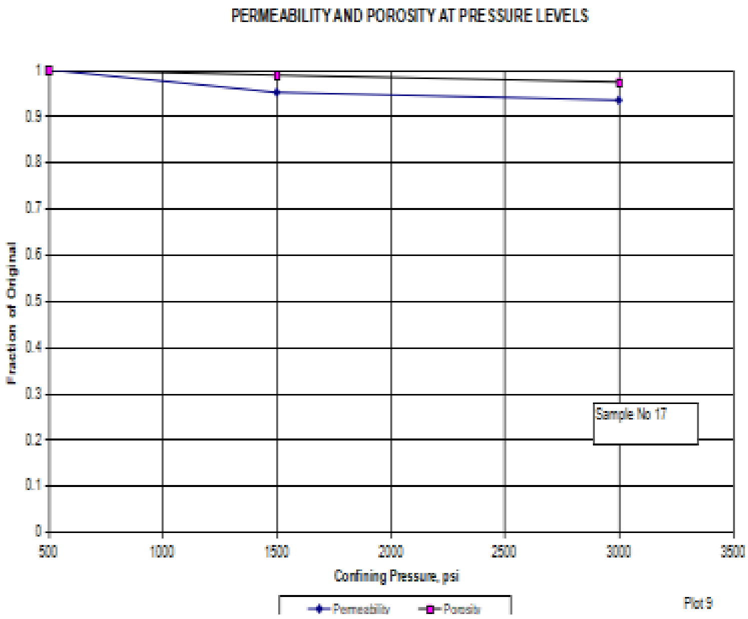

Figure 10 Graph of sample P17 smallest permeability reduction

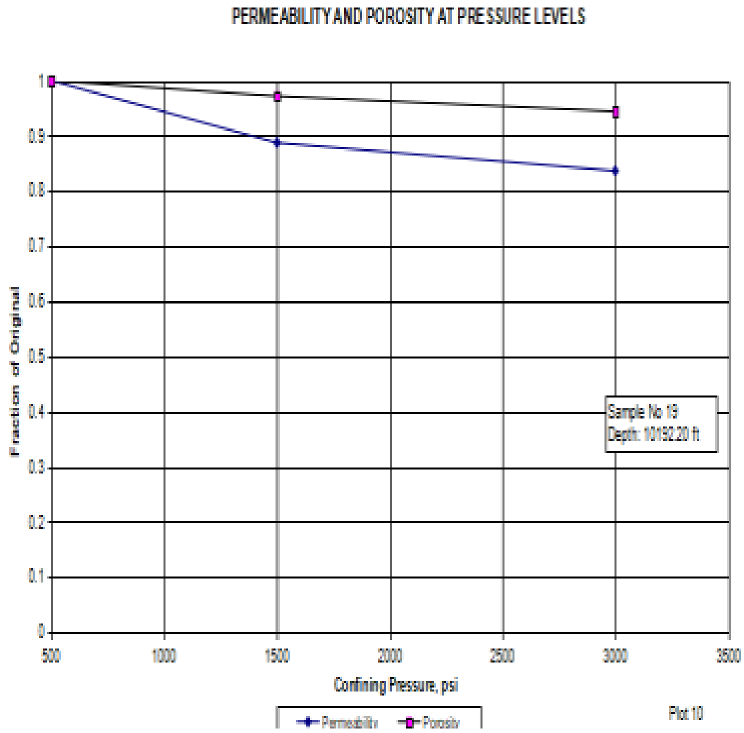

Figure 11 Graph of sample P19 smallest permeability reduction

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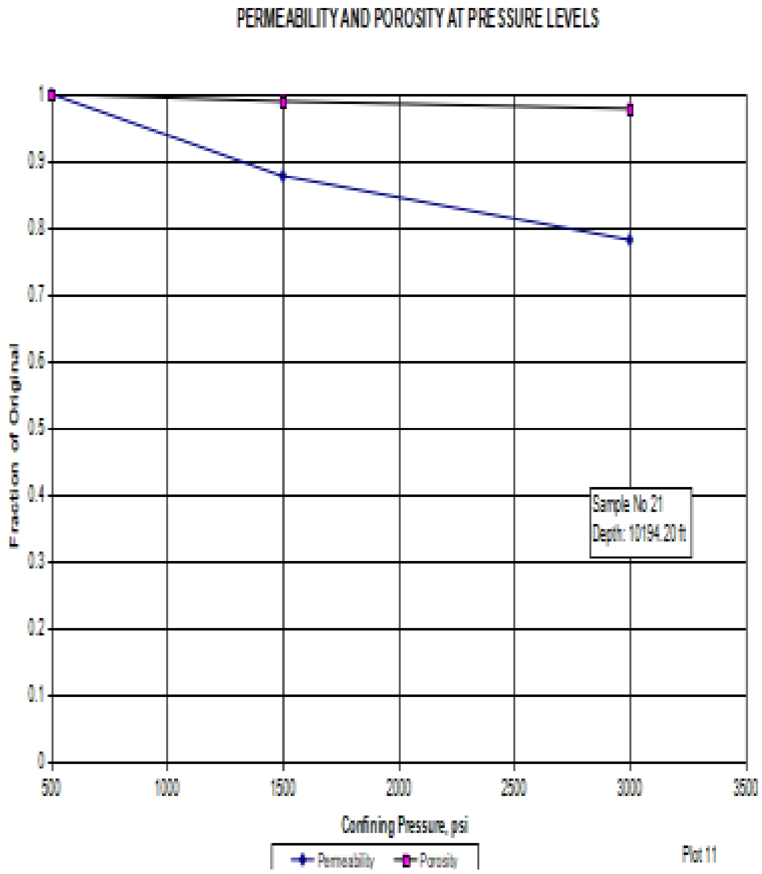

Figure 12 Graph of sample P21 smallest permeability reduction

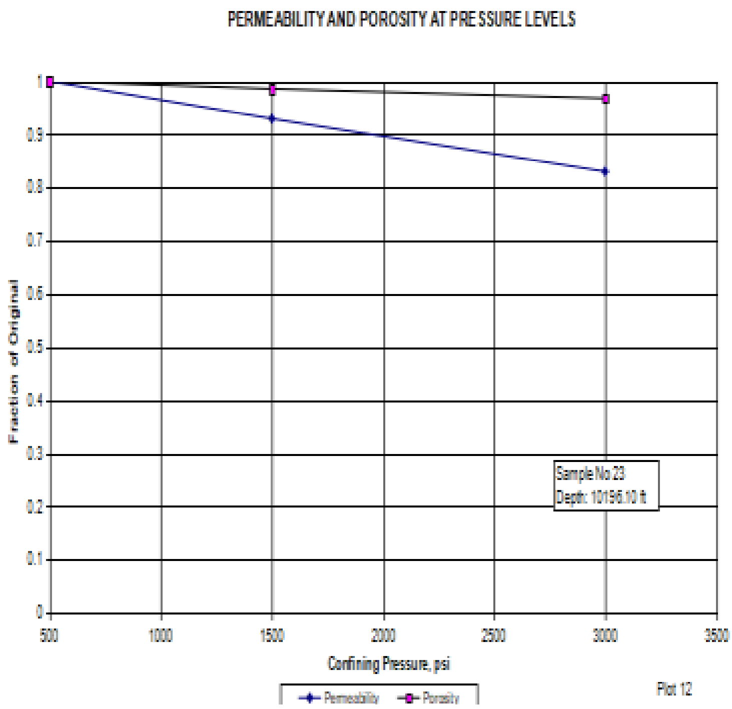

Figure 13 Graph of sample P23 smallest permeability reduction

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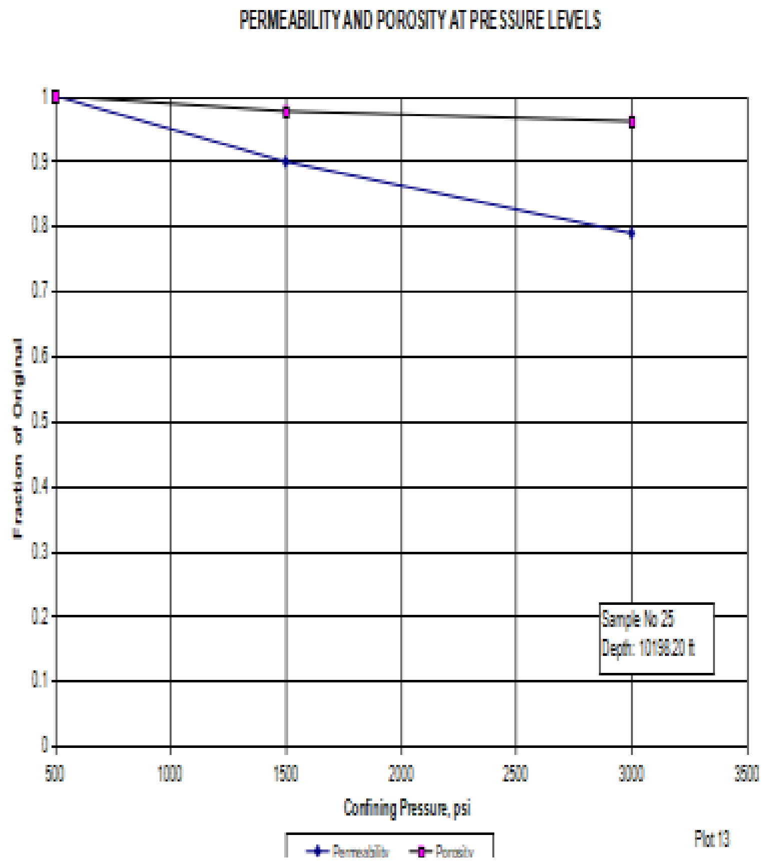

Figure 14Diagram of sample P25 smallest permeability reduction

Influence of Pressure on Porosity

To analyse the impact of simulated overburden pressure on core porosity for sandstone rock in the Niger Delta, the porosity data's are standardize by dividing the resultant porosity at any applied pressure to the initial porosity at 500psi. From the above chart, as simulated overburden pressure increases, the initial porosities of P1, P3, P5, P7, P9, P11, P13, P15, P17, P19, P21, P23, P25, P27 and P29 samples are reduced respectively. Figure 9 to Figure 14 above. It ought to be noted that, simulated overburden pressure has less effect on porosity in contrast to permeability under similar pressure conditions. As simulated over burden pressure increases, volume of pores and pathways becomes tighter which vividly influence the permeability owing to the closure of pathways. Applied simulated overburden pressure does not influence porosity noticeable, in that most important parameter of the porosity is the volume of pores which is not influence evidently. Therefore, simulated overburden pressure of porosity is anticipated to be way less, in respect to permeability under similar pressure conditions.

Model to Portray Pressure and Porosity Values

Table 2 below shows the values of both power law model and exponential models, and also the goodness of fit of both models.It appears that, the power law model describe porosity under simulated overburden pressure, as it values are more influence greater in contrast to exponential model.

Table 2 Estimation of various specimen using power law and exponential equations (model)

Sample ID	Power law equation		Exponential equation	
	Applied Pressure		Applied Pressure	
	a	R^2	ϒ(Psi^{-1})	R^2
P1	0.0396	0.999	2.84×10^{-6}	0.926
P3	0.0524	0.999	3.75×10^{-6}	0.953

P5	0.0237	1	1.69×10^{-6}	0.943
P7	0.0209	0.993	1.49×10^{-6}	0.974
P9	0.0169	0.996	1.21×10^{-6}	0.911
P11	0.0197	0.999	1.41×10^{-6}	0.950
P13	0.0279	0.997	1.99×10^{-6}	0.913
P15	0.0204	0.938	1.46×10^{-6}	1
P17	0.0151	0.954	1.07×10^{-6}	0.999
P19	0.0319	0.981	2.28×10^{-6}	0.988
P21	0.0123	0.982	8.72×10^{-7}	0.987
P23	0.0181	0.961	1.29×10^{-6}	0.997
P25	0.0221	0.999	1.58×10^{-6}	0.950
P27	0.0348	1	2.49×10^{-6}	0.944
P29	0.0261	0.997	1.87×10^{-6}	0.964

From the experiments conducted so far, we can see that simulated overburden pressure has more influence on permeability much more than porosity. In conclusion, simulated overburden pressure has more influence on pore throats (pathway) in comparison to pore size (volume).

V. CONCLUSION

Following literature review, laboratory analysis, high technology application and equipment utilization, thisstudy concludes that when simulated overburden pressure increases, it will significantly decrease permeability and porosity values. This is because simulated overburden pressure had greater influence on pore throats (flow pathways) in contrast to pore size (volume).The values of permeability was greatly influence more, than that of porosity under similar pressure conditions for all core specimen. Thus, in specimen where the permeability is low, there is possibility of losing some of the connected flow pathways as pressure increases.Also, simulated overburden pressure had more influence on pore throat size (pathways) in comparison to pore size (volume).Thus, in specimenwhere the permeability is high, simulated overburden pressure can make the pore tighter but still there is still a possibility of fluid flow.

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