Reservoir Potential of the Kerri-Kerri Formation in Gar Area, Alkaleri LGA, Bauchi State

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Abstract

This study compared two methods, the Falling head permeameter test and the Granulometric analysis data in determining the reservoir potentials of the Kerri-Kerri Formation in Alkaleri LGA, Bauchi State. Rock samples were collected from the Kerri-Kerri Formation in Gar locality to determine the congruence and or discrepancy between two methods. Permeability was determined from both granulometric data and the falling head permeameter test, while porosity was determined from the granulometric data. Cumulative frequency curves of sediments collected from four locations (L1, L2, L3 and L4) were collected for this work. Sieve analysis data of samples L1, L2, L3 and L4 yielded permeability values of 1.0167 × 10-10 Darcy, 2.3851 × 10-10 Darcy, 2.5798×10-11 Darcy and 7.82×10-5 Darcy respectively. Falling head permeameter tests for the samples gave permeability values of 1.7369 × 10-19 Darcy, 2.082 × 10-19 Darcy, 2.082×10-19 Darcy, and 9.86×10-13 Darcy respectively. Permeability results of the two methods indicate relatively close values for samples L1 and L2. Generally, values obtained from using the sieve analysis data showed slightly higher effectiveness in determining permeability compared to the falling head permeameter tests. From the granulometric analysis data, porosity of the formation from locations L1, L2, L3 and L4 are 11.17%, 15.52%, 17.04% and 16.22% respectively.

INTRODUCTION

The Kerri-Kerri Formation is located in the E–W tertiary extensional tectonism resulting from the reactivation of Pan-African orogeny (Zaborski et al., 1997; Dike, 1993). The geology and lithology of the Kerri- Kerri Formation can be characterized by medium-to-coarse-grained sands, pebbly coarse sands, siltstones, clays, medium-to-fine-grained sands, laterites and conglomeratic lenses (Samaila et al., 1999, Adegoke et al., 1986; Dike, 1993). The Kerri-Kerri Formation is made up of sedimentary rock which constitutes the Gongola sub-basin and Northern Benue Trough. In addition, the Kerri-Kerri Formation sediments were derived from Nigeria's central basement complex, including the Younger Granites of Jos Plateau (Dike 1993). More so, the Cretaceous sediments were derived from the east, while the tertiary sediments were obtained from the west of the Northern Benue Trough. Also, the lithofacies were designated into facies which will help in defining the depositional environments (Shettima et al.2016).

The Kerri-Kerri Formation is made up of Continental areas ranging from lacustrine to deltaic and obtained from the rocks weathering basement and its sedimentary (Carter et al., 1963). More so, the formation constitutes an outcrop unit area of more than 3,000 km2 in the north and south parts of Nigeria (Olabode et al., 2015). The Kerri-Kerri Formation lies in the basement complex in the western part of the Kerri-Kerri Plateau and is masked by abundant alluvial deposits (Carter et al., 1963). In addition, the thickness of the Kerri-Kerri Formation ranges from 200 m to 300 m as reported by (Carter et al., 1963). The Kerri–Kerri Formation consists of flat-lying to dip conglomerate, sandstone, siltstone and clay which overstep the Gombe Sandstone (Carter et al., 1963). The Kerri-Kerri Formation can also be characterized by the grade of the sandstone and felspathic sediments which is coarser (Carter et al., 1963). An increase in the sandstone content and sand grains content at the lower part of the Kerri-Kerri Formation could be interpreted as the shallowing of the basin during sediment fill (Odedede and Adaikpoh, 2011).

The study area is in Gar, located in the Alkaleri Local Government Area of Bauchi State. It is in the southeastern part of Bauchi town between latitude N 10^0 04' 10.0" and longitude E 10^0 15' 52.0". Gar is located along the Dindima-Yankari National Park road. It is just a few kilometers away from the game reserve (Fig. 1).

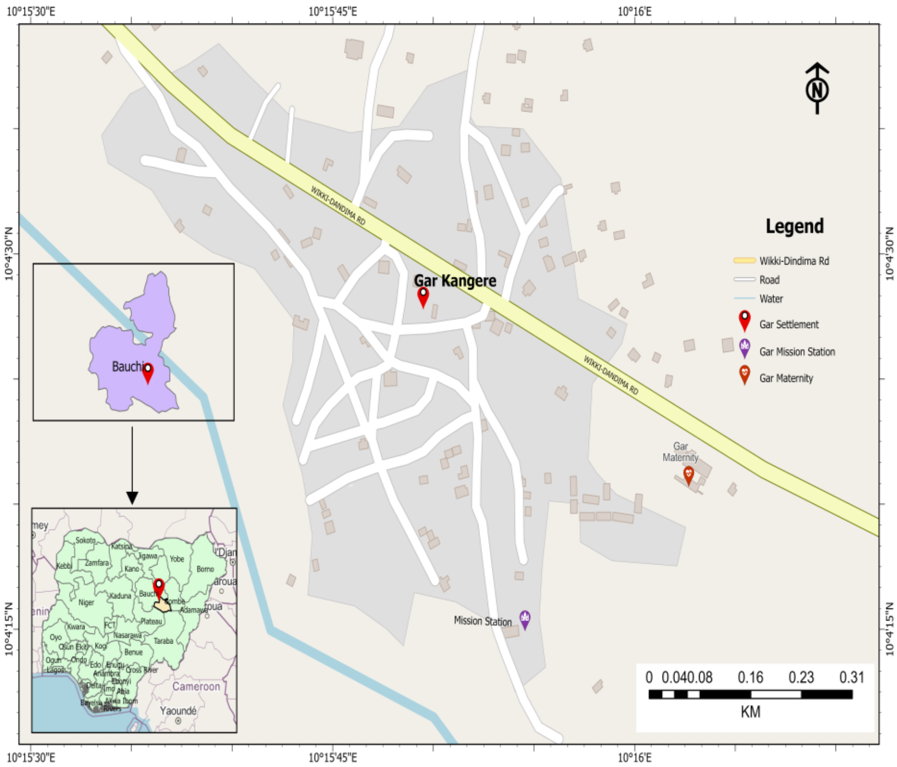

Figure 1: Location map of the Study area

General Geology of the Area

The area studied is limited to the upper Benue trough and it is divided into three namely; the Yola arm, the Gongola arm and the Lau basin. The Upper Benue trough is in the Northern part of the basin and is characteristically Y-shaped. One arm of the Y-shape is the east-west trending Yola arm the other one is the north-south trending Gongola arm (Gongola Basin) Dike (2002) and the third arm is the northeast-southwest trending Lau or Muri –Lamurde arm which gives it the Y-shaped characteristics.

The first work on the Upper Benue Trough was carried out by Carter *et al.*, (1963). However, it was mapped by Falconer (1911). Carter *et al.*, (1963) identified about eleven lithogenetic formations in the Upper Benue Trough. Significantly the geology and stratigraphy of the Upper Benue Trough have been described by Reyment (1997) and Dike (2002).

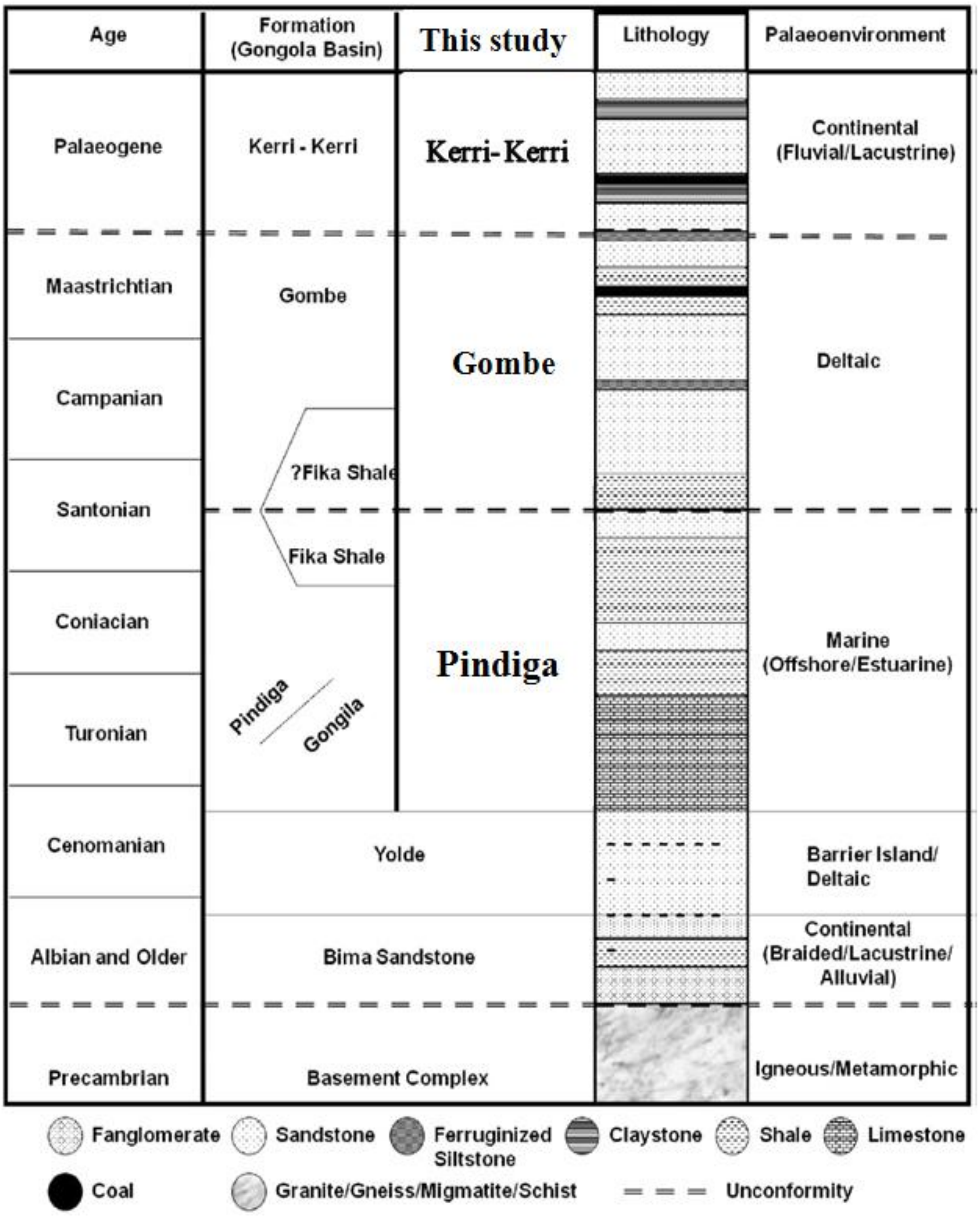

Figure 2: Stratigraphic units of the Northern Benue Trough (Abubakar et al., 2011).

MATERIALS AND METHODS

3.1 Granulometric (Sieve) analysis method

Rock samples from four locations (L1, L2, L3, and L4) were used in conducted Falling Head Permeameter tests and granulometric analysis (sieve analysis) with the aim of determining permeability and porosity values of the Kerri-Kerri Formation in the study area.

Particles of sediment are not spherical; they are seldom regular in shape and vary greatly from each other. This makes it difficult to determine their size which is accomplished through their irregular shape. The methods of measurement are based on the assumption that the particles are spheres, or that the measurement can be expressed as diameters of equivalent spheres. The method of mechanical (granulometric) analysis depends on the dominant size range of the particles of sediment.

Graphical presentation permits the rapid and easy comparison of a large number of sediments and renders it simple to point out the similarities and differences. Data could be represented by a histogram, a simple frequency curve and a cumulative frequency curve. A simple frequency curve is a smooth curve that is mathematically related to the histogram. It cannot be plotted directly from the analytical data but is obtained from the histogram by drawing a smooth curve through the bars with the area between two adjacent ordinates unchanged.

In cumulative curves with arithmetic ordinate, the ordinate (vertical scale) is an arithmetic scale running from 0-100%. The grain size is plotted on the abscissa with coarser particles to the left. Size may be represented in millimeters in which case semi-log paper is used, or in phi units whence it can be drawn on ordinary mm paper. The analysis normally forms an S-shaped curve. Cumulative curves with probability ordinates have the vertical scale divided according to the probability scale, which is very condensed in the middle (30-70%) and very much extended at the ends (under 10% and over 90%). This curve is preferred since sediments, being natural products; tend to approach the "normal probability distribution" in which most of the particles are clustered about a given size. A normal symmetrical probability distribution, when plotted on probability paper, results in a perfectly straight line, thus the curve shows a departure from the normality of a grain size distribution

The method most commonly used involves plotting the cumulative curve and reading the diameter represented by various percentages. The fundamental measures are measures of the average size; measures of uniformity or sorting; measures of asymmetry or skewness; and measures of kurtosis or peakedness.

Mean Diameter "Md" (Trask). The median diameter is the size at which 50% of the particles (by weight) are coarser and 50% are finer; it is the diameter (size) corresponding to the 50% line on the curve, it may be expressed in mm or phi units. The median diameter is the easiest to determine but has no meaning in bimodal sediments. The graphic mean is calculated by the formula: $Mz=1/3\ (\phi16+\phi50+\phi84)$. It is much superior to the median because it takes the mean of the diameter at 3 points on the curve; it is usually expressed in phi units.

3.1.1 Permeability from Granulometric Data

To calculate permeability from graphic mean size data, the equation below was used. "***Equilibrium Constant." Chemistry libre text, (2023)".***

K = C $(D_{10})^2$

Where K = permeability (cm/s).

C = Graphic coefficient

D_{10} = Grain size mesh equivalent of the 10th cumulative weight percentage (mm)

K = 1.33 $(0.24)^2$

K = 0.0766 (cm/s)

3.1.2 Porosity from Granulometric Data

To calculate porosity from graphic mean data, the equation below was used (Kozheny-Carman equation)

K = $\frac{g}{v} C_t[\emptyset - 0.13]^2 {D_{10}}^2$ i

Where K = permeability (cm/s)

G = standard gravity (m/s) (9.8)

C_t = sorting coefficient ranges from (6.1 x 10^{-3} - 10.7 x 10^{-3})

$\emptyset =$ porosity in fraction (%)

V = velocity (1 m/s)

D_{10} = Grain size mesh equivalent of the 10th cumulative weight percentage (mm) obtained from the graph of frequency curve in mm.

From equation (i), above

porosity = ($\emptyset$) = $\sqrt{\frac{KV}{g C_t {D_{10}}^2}}$ + 0.13

Where K = permeability (cm/s)

G = standard gravity (m/s) (9.8)

C_t = sorting coefficient ranges from (6.1 x 10^{-3} - 10.7 x 10^{-3})

V = velocity (1 m/s)

3.2 Falling Head Permeameter Test Method

To conduct the falling head permeameter test, water was allowed to flow from the stand pipe through the de-airing tank stocked full of the disaggregated samples of one locality at a time. Head loss was measured and the discharge rate was calculated. The result obtained was used in determining the permeability of the formation. Some of the accessories used in conducting the test include:

a. Pressure gauge (b) De-airing tank (c)Standpipe (d) Corer (e)Stop-watch (f) Calculator

Plate 1: Falling Head Permeameter test apparatus

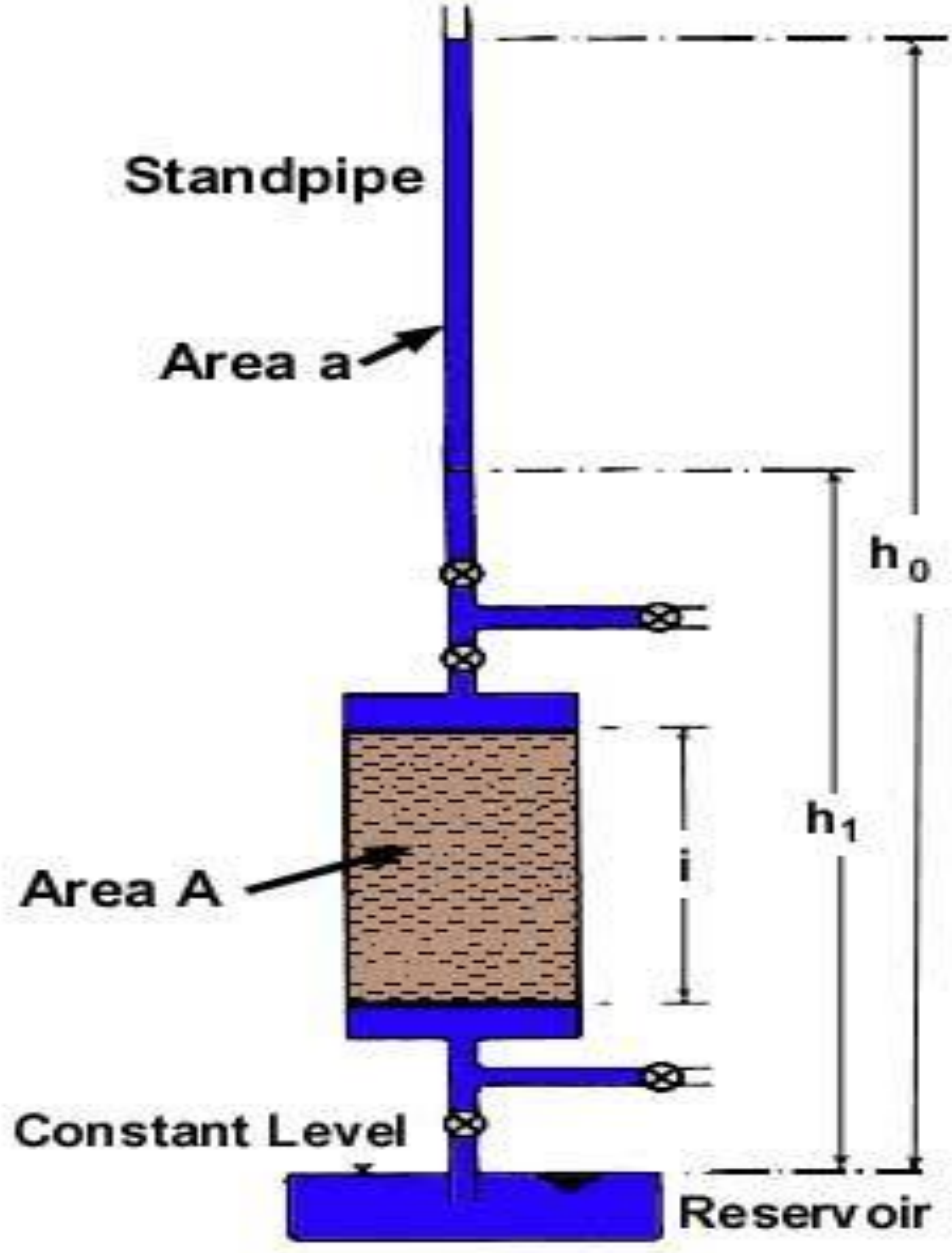

Plate 2: Simplified Falling Head permeameter test Apparatus

3.2.1 Permeability

To determine the permeability of the Kerri-Kerri Formation from the study area, using results of the falling head permeameter, the formula (Who is the author?)below was used.

K=$\frac{2.30aL}{At} log10 \frac{h1}{h2}$

where h_1 is the initial head
h_2 is the final head
a is the cross-sectional area of the standpipe
A is the cross-sectional area of the sample
L is the length of the sample
t is the time

RESULT and Discussion

4.1.1 Falling Head Permeameter Results

Table 1 shows the datum height (mm), sample (mm), time (minutes) and height ratios readings obtained from the Falling Head Permeater test of the 4 samples collected from the study area. Permeability test for samples L1-L4 area presented as P1T1, P1T2, P1T3 and P1T4.

Table 1: Result Obtained from Falling Head Permeability Test for samples L1, L2, L3 and L4

Datum height(mm)	Sample (mm)	Time(minute)	Height ratio
H1= 1665.0	1432.0	(1-2)	H1/H3= 1.51
H3=1184.3	951.3		
H2=865.0	632.0	(3-2)	H1/H2=1.51
TOTAL			Log10= 1.51=0.17761

Darcy law

Q = $KA \frac{\Delta P}{\mu L}, \frac{m^3}{s}$ (i)

However, in linear flow,

Superficial velocity can be expressed as thus,

$V_S = \frac{Q}{A}, \frac{m}{s}$ (ii)

Also, expressing viscosity as dynamic viscosity (Ƞ), Pascal, equation (i) becomes

$V_S = \frac{K}{\eta}\frac{\Delta P}{L}, \frac{m}{s}$ (iii)

Where; V_S = fluid velocity (superficial velocity) $(\frac{m}{s})$

K = permeability of a medium (m^2)

Ƞ = dynamic viscosity of fluid (Pa. s)

ΔP = applied pressure difference (Pa)

L = thickness of the bed of porous medium (m)

KT=33.84 x $\frac{\text{aL}}{\text{At}}$xlog10 $\frac{h1}{h2}$x 0.00001 m/s
a=7.07 l= 130mm A=7854

P1T1 Permeability test for sample L1

Total t=final time-initial time
Final time=50.06minute
Initial time=10.25minute
KT=33.84 X $\frac{7.07 \text{ x } 130}{7854(50.06-10.25)}$ x 0.17761 x 0.00001 m/s
KT = $\frac{0.05524m/s}{7854\ x\ 39.81}$
KT= 0.000000176m/s = 1.736985008 x 10^{-19} Darcy

P1T2 Permeability test for sample L2

Total t=final time-initial time
Final time=37.49minute
Initial time=4.24minute
KT=33.84 X $\frac{7.07 \text{ x } 130}{7854(37.49-4.24)}$ x 0.17761 x 0.00001 m/s
KT = $\frac{0.05524m/s}{7854\ x\ 33.25}$
KT= 0.000000211m/s = 2.082408163 x 10^{-19} Darcy

P1T3 Permeability test for sample L3

Total t=final time-initial time
Final time=54.26minute
Initial time=20.05minute
KT=33.84 X $\frac{7.07 \text{ x } 130}{7854(54.26-20.05)}$ x 0.17761 x 0.00001 m/s
KT = $\frac{0.05524m/s}{7854\ x\ 34.21}$
KT= 0.000000205m/s = 2.082408163 x 10^{-19} Darcy

P1T4 Permeability test for sample L4

Total t = final time – initial time

Final time = 50.06

Initial time = 10.25 minutes

KT = 33.84 × $\frac{7.07 \times 130}{7854\ (50.06-10.25)}$ $\times 0.17761\ \times 0.00001\ m/s$

KT = $\frac{0.05524\ m/s}{7854\ \times 39.81}$

KT = 0.000000176 m/s
To convert from m/s to Darcy = 9.869233 x 10^{-13}Darcy

4.1.2 Granulometric data for samples L1-L4

Granulometric data presented in Tables 1-4 are data obtained from mechanical analyses of samples L1-L4. Figures 1-4 are cumulative frequency curves obtained from plotting mesh sizes and cumulative weight % of sample L1-L4. The graphic mean data obtained from the the cumulative frequency curves were used in determining permeability and porosity of the formation in Gar locality.

Table 2: Granulometric (Sieve Analysis) Data for Sample L1

Mesh size (mm)	**Phi (ϕ)**	**Mass retained (g)**	**% of mass retained**	**Cumulative Wt. % of mass retained**
4.75	-2.25	-	-	-
3.35	-1.74	-	-	-
2.36	-1.24	0.29	0.20	0.20
1.18	-0.24	12.83	8.77	8.97
0.85	0.23	19.66	13.47	22.44
0.425	1.23	40.41	27.68	50.12
0.30	1.74	8.75	6.00	56.12
0.212	2.24	9.63	6.60	62.72
0.106	3.24	27.95	9.82	72.54
0.075	3.73	10.00	10.64	83.18
0.063	3.98	6.37	8.71	91.89
PAN		10.10	7.92	99.81
TOTAL		145.99		

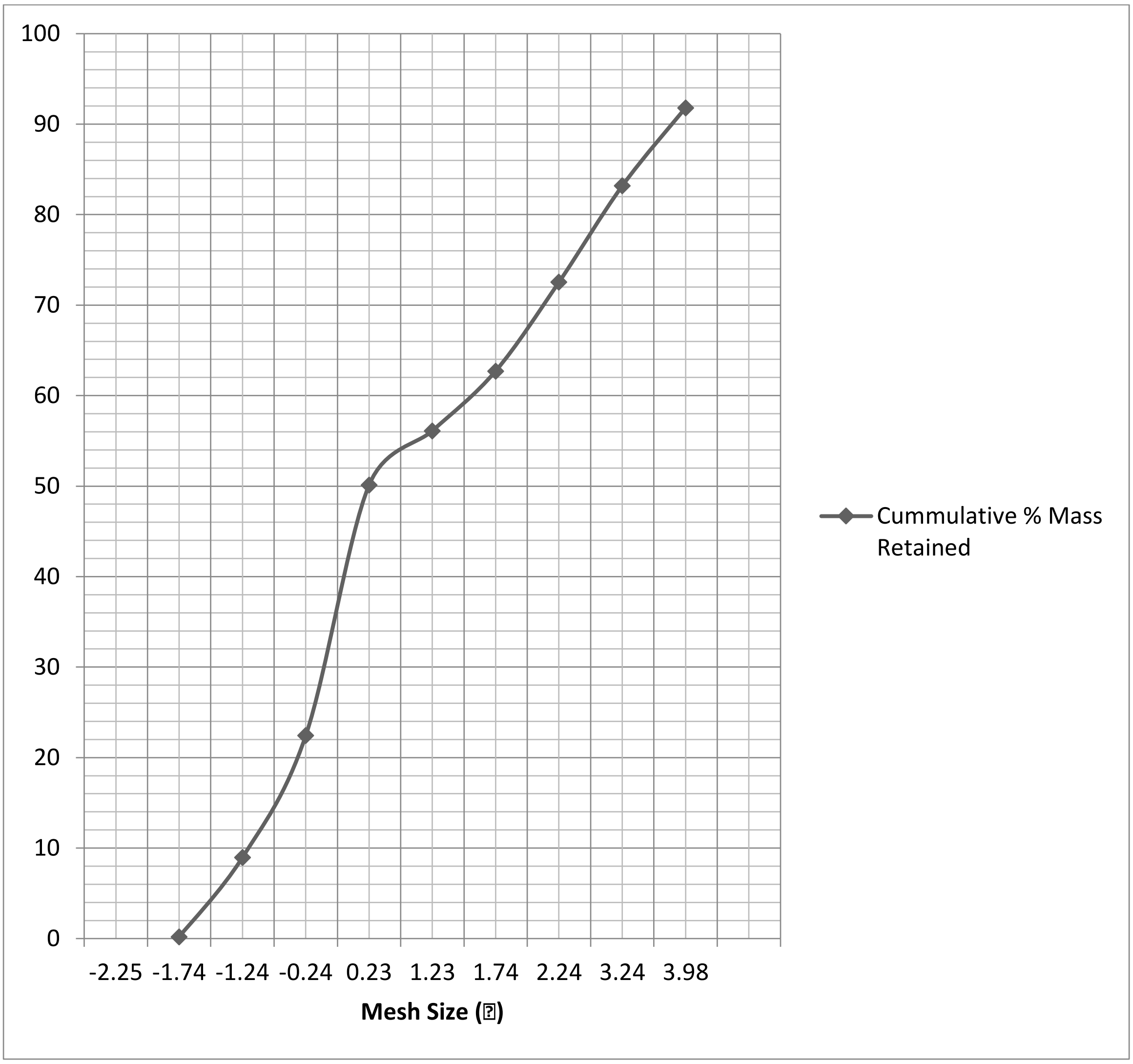

Figure 4: Cumulative Frequency Curve for sample location (L1)

Graphic mean = 1/3 (ϕ16+ ϕ50+ ϕ84)
= 1/3 (-0.6+0.2+2.4)
= 0.67

Permeability from graphic mean = K = C $(D_{10})^2$

Where D_{10} is obtained from the graph of cumulative frequency curve sample L1

K = 0.67 $(1.24)^2$ = 1.0302 (cm/s) = 1.0167 × 10^{-10} Darcy

Porosity = (∅) = $\sqrt{\frac{KV}{gC_tD_{10}{}^2}}$ + 0.13

∅ = $\sqrt{\frac{1.0302 \times 1}{0.091917728}}$ + 0.13 = 11.17

∅ = 11.17%

4. Porosity = (∅) = $\sqrt{\frac{KV}{gC_tD_{10}{}^2}}$ + 0.13

∅ = $\sqrt{\frac{2.6754 \times 1}{0.091917728}}$ + 0.13 = 17.92

∅ = 17.92%

Permeability test carried out on the studied area showed low permeability, indicating that the soil in the area has a low permeability. The sieve analysis test carried out also confirmed that the studied areas of sample locations (L1, L2, L3 and L4) have low porosity and permeability respectively.
The sieve analysis results for location (L1) had a permeability of 1.0167×10^{-10} Darcy (graphic mean), . In Location (L2), the permeability obtained was 2.3851×10^{-10} Darcy (graphic mean), (L3) permeability obtained is 2.5798×10^{-11}Darcy (graphic mean) and (L4) permeability is 7.82×10^{-5} Darcy (graphic mean) .Porosity of the location (L1) was obtained to be 11.17%,and 17.92%. While the porosity (L2) was 15.52%, (L3) obtained to be 17.04%, and (L4) was 1.622%. The porosity result showed the locations (L1, L2 and L4) had low porosity.

The permeameter results obtained showed that location L1 had a permeability of 1.7369×10^{-19} , L2 had a permeability of 2.082×10^{-19}, L3 had a permeability of 2.082×10^{-19} Darcy and L4 a permeability of 9.86×10^{-13} Darcy.The results analysis obtained showed that the location (L1 and L2) for both the sieve analysis and permeameter analysis are relatively close. The potential of hydrocarbon in those locations (L1 and L2) cannot be ascertained. From the permeability test conducted for the constant head test of the three samples collected using a corer, the result shows that the sample has a grain type of silty clay to clay with a coefficient of permeability (K) below 10^{-7}m/sec, which also indicates that the drainage property of the materials forming the sample also defined specific yield of the sample is very poor which is further said to be practically impermeable as shown in table 5-6.

Conclusions

In conclusion, this study compared the effectiveness of the Falling Head Permeameter test and Granulometric analysis data in determining the reservoir potentials of the Kerri-Kerri Formation in Alkaleri LGA, Bauchi State. The results showed that both methods yielded permeability values, with the Granulometric analysis data exhibiting slightly higher effectiveness. The porosity values obtained from the Granulometric analysis data indicated a moderate to good reservoir potential. The study demonstrates the importance of using multiple methods to determine reservoir potentials and highlights the potential of the Kerri-Kerri Formation for hydrocarbon exploration and development. The findings of this study contribute to the understanding of the reservoir properties of the Kerri-Kerri Formation and provide valuable insights for future research and exploration activities in the region."

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