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The Use Of Length/Diameter Ratio To Determine The Reliability Of Permeability Data From Core Samples

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Abstract: *Petroleum reservoir quality is governed by two important petrophysical parameters namely porosity and permeability. The length of test sample used for permeability measurement can affect the result. To determine the permeability of core samples, the length and cross-sectional area of the sample must be accurately measured. Hence, there should be a standard for testing in the laboratory. For every reservoir, it must be determined to know if the reservoir is permeable or not. The key factors that control permeability data are length and diameter of the core. In testing for reservoir that has not been evaluated, the sample length/diameter ratio is critical to the result that will be achieved. Therefore, it is imperative to determine a reference for testing in all laboratories. This study is conducted in order to confirm an acceptable length/diameter ratio that will serve as a guide during preparation of test samples before commencement of permeability measurement in the laboratory. The length/diameter ratio of core plugs was varied and their permeability determined experimentally using gas permeameter.*

Key words: *Porosity, Permeability, Darcy law, Core sample, permeameter*

I. INTRODUCTION

The reliability of permeability data obtained from core samples is critical to the measurement of permeability using core data. Different length/diameter ratios of core plugs will be used to ascertain a reliable permeability data which can be further used as a standard in comparison with the one obtained from institutions or industrial laboratories.

A rock is said to be permeable if a fluid can pass from one surface to another under the influence of external forces such as gravity and fluid pressure). The definition of rock characterization and permeability is based on measurable quantities as put forth by Darcy**.** Since, the early stage of oil well production, engineers have recognized that most reservoirs vary in permeability and other rock properties in the lateral direction. First attempt to quantify the areal permeability distribution from observed differences in well production history was that of Kruger in 1961. There are several factors that must be considered as possible sources of error in determining reservoir permeability. From these factors, the most critical is the Core sample which may not be representative of the reservoir rock because of reservoir heterogeneity. Moreover, the core recovery may be incomplete. Permeability of the core may be altered when it is cut, or when it is cleaned and dried in preparation for analysis. This problem is likely to occur when the rock contains reactive clays. Sampling process may be biased. There is also the temptation to select the best parts of the core for analysis, which may not be a good representation of the entire system.

II. MATERIALS AND METHODOLODY

Measurements made using gas (Nitrogen) are preferable because it minimizes fluid-rock reaction and also it is convenient. To determine the reliability of permeability data from core samples, the length and cross-sectional area of the sample must be accurately measured and standardized. A core plug of known length and diameter is important in the determination of actual value of permeability.

A core is a sample of rock from the section generally obtained by drilling into the formation. Normally, cores samples are prepared by cutting cylindrical plugs using a drill press and one-half inch diameter bit. A total of fifty sample plugs were drilled using a drill press of 1½ inches diameter drill bit to drill through a slabbed core surface up to a depth of about 3inches with liquid nitrogen to ensure integrity of the sample. The samples were encapsulated with nickel foil and stainless steel mesh at each end face to prevent grain erosion and then pressurized up to 200psi to maintain sample integrity.

Samples were placed in soxhlet equipment, and toluene was used to clean the oil and the system was allowed to reflux several times until the refluxed solvent is observed to appear colourless. Thereafter methanol was used to replace the toluene and remove salt. The samples after cleaning are then placed in a conventional Oven to dry to a constant weight at about 100^0C or 110^0C for clean sandstone and 60^0C for shaly sandstones until the dry weight was stable. After drying, the Samples are cooled in a desiccators to room temperature prior to measurement.

The gas permeameter is designed to measure the permeability of consolidated cores, when both gas viscosity and core dimensions are known.

The equipment used for gas permeability measurement include: Permeameter, Nitrogen source, Stopwatch, Core holder, Bubble tube and Digital calliper. The temperature is recorded at the beginning of the experiment, The dried samples length and diameter are measured using a digital caliper. Each dried sample is placed in a core holder assembly which consist of rubber boot and stems. The core holder is connected with connecting lines to a gas cylinder. The core is pressurized to 400psi overburden pressure using compressed air. Nitrogen gas is then flown through the connecting line to the sample in the core holder using a regulator to adjust flowing pressure until a laminar flow rate is established.

The resultant flow pressure is recorded from the gauge mounted on the core holder. The gas coming out of the sample drives a soap bubble through a burette. The time it takes for the bubbles to pass through 30cm calibration point on the burette and the volume of gas flow through the burette is measured and recorded using a stopwatch. The test pressure determined by the air regulator is recorded. The flow rate of the gas is determined. The viscosity of the gas is recorded and temperature taken again the barometric pressure at the time of measurement is recorded. The average length of sample and diameter is record and then using Darcy's equation the permeability of the core sample is calculated.

All the samples tested by the procedure described above are re-determined with a decreased length, while keeping the diameter constant, thereby generating a new length/diameter ratio. The permeability results determined by those 'new' samples are compared with the original results obtained from the one with maximum length.

Porosity Determination (Pore volume and Bulk volume)

1. Each plug sample was individually placed into a rapid access core holder connected to Ultrapore equipment.
2. Helium at a known reference pressure (P_1) and Volume (V_{Ref}) was isothermally expanded into the sample's pore space (V_{Pore}) and after pressure stabilization; the pressure (P_2) was recorded.
3. The sample's pore volume is derived from basic Boyles law.
4. The sample's true pore volume was obtained by deducting the volume of screens (for mounted samples only).
5. The bulk volume of the sample was determined using the callipered length and diameter of the samples. Grain volume + pore volume.

Porosity is reported as a percentage of the bulk volume as below:

$$\phi = \frac{Pore\,Volume}{Bulk\,Volume} * 100 \qquad 1$$

where Ø is porosity, %

RESULTS AND DISCUSSION

Fluid used: Nitrogen gas; Calibrated volume of gas in the burette = 30cm

Temperature T= 25^{o}C; Diameter of core = approximately 3.7cm

Varying Length used, L; Viscosity of the gas used = 0.0177cp

$$K = \frac{2000 B \mu g Q L}{A\left(\left(Pu+B\right)2-\left(Pd+B\right)2\right)} \quad 2$$

The result is computed using Microsoft excel and tabulated in the appendix. From the results obtained using Darcy's law, the direct proportional relationship between the effects of permeability using length variation is observed. At a specified temperature of 25^{0}C with varying pressure for different core samples, the permeability value is directly proportional to the length decreases (Assuming constant volume timed), therefore, the plot of permeability, K against standard length, L gives a scatter plot variation. It is also observed in the plot that there is higher concentration of permeability around 4500millidarcy.The plot of permeability against porosity also show the trend of high permeability with porosity. (See Figure 1)

When the length of the core was changed in order to have a length/diameter ratio of 1:1, there was a change in the permeability value, showing the effect of length variation. The permeability concentration changes from 4500millidarcy to 3500millidarcy when the length was reduced. The cross plot of permeability against porosity also shows that it is permeable around 3500 millidarcy, with given porosity constant.

When the length of the core was changed, to a ratio of 0.5:1, the permeability value drastically dropped, which a great change on the permeability. The plot of permeability against length shows that permeability value concentrated at 1500millidarcy which is far different from the standard length used. The cross plot of permeability against porosity also shows that the permeability is low due to the length of the core that has been reduced beyond limit.

Generally, it is observed from the result that when the length of the core sample is reduced permeability decreases and vice versa. The permeability obtained when standard length is used is almost the same as when the length is equal to diameter, but when the ratio was changed to 0.5:1, the permeability data seems to be unreliable.

III. CONCLUSIONS

This precisely agreed that for a permeability data to be reliable, the minimum length/diameter ratio should be 1:1, which shows that permeability is proportional to length of a core. The minimum length of the tested sample having a specified diameter approximately 3.7cm core has been determined and established which should be a reference for testing in the laboratory noting that samples having length smaller than this established value would give an erroneous result

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NOMENCLATURE

t = Time of each core samples, sec, v = Calibrated volume, cm^3 , K_g= Permeability to gas (mD), B= Barometric pressure, atm, Q= Gas flow rate at B, cc/sec, μ_g = Gas viscosity, cp, L= Sample length, cm , P_u= Upstream Pressure, atm, P_d = Downstream Pressure, atm

APPENDIX

Table 1: Permeability of Samples with Length Conforming with Standard Practice

Sample No.	Pressure (P) (atm)	barometric pressure (B) (atm)	Temperature T (^{0}C)	Gas viscosity C_p	volume timed (cc)	Average time (s)	Length (cm)	Diameter (cm)	Area (cm^2)	Flow rate Q (cc/s)	Perm. K (millidarcy)
53	0.001207	1.023027	25	0.0177	30	72.24	5.933	3.703	10.77094	0.404069767	3262.023
77	0.001114	1.023027	25	0.0177	30	67.04	5.561	3.706	10.7884	0.435411695	3564.082
5	0.001134	1.023027	25	0.0177	30	55.17	5.875	3.713	10.82919	0.529091898	4477.777
16	0.000888	1.023027	25	0.0177	30	67.74	5.522	3.719	10.86422	0.430912312	4363.737
43	0.001011	1.023027	25	0.0177	30	56.75	4.71	3.714	10.83503	0.514361233	3912.611
58	0.000815	1.023027	25	0.0177	30	59.17	5.919	3.711	10.81753	0.49332432	5859.971
73	0.000545	1.023027	25	0.0177	30	56.08	5.431	3.684	10.66069	0.520506419	8609.572
88	0.000864	1.023027	25	0.0177	30	65.32	4.437	3.736	10.96377	0.446876914	3703.340
8	0.000496	1.023027	25	0.0177	30	54.76	4.231	3.74	10.98726	0.533053324	7323.364
57	0.000643	1.023027	25	0.0177	30	52	5.565	3.768	11.15239	0.561346154	7708.214
61	0.000717	1.023027	25	0.0177	30	71.81	6.443	3.731	10.93444	0.406489347	5910.750
12	0.000864	1.023027	25	0.0177	30	61.85	5.42	3.74	10.98726	0.471948262	4767.388
68	0.001158	1.023027	25	0.0177	30	61.56	6.084	3.703	10.77094	0.47417154	4091.571
20	0.00079	1.023027	25	0.0177	30	64.46	6.082	3.732	10.94031	0.45283897	5638.184
6	0.001011	1.023027	25	0.0177	30	54.51	5.662	3.737	10.96964	0.535498074	4836.631
51	0.01198	1.023027	25	0.0177	30	64.57	5.289	3.781	11.22948	0.452067524	312.751
41	0.001907	1.023027	25	0.0177	30	60.3	4.312	3.708	10.80005	0.484079602	1792.206
48	0.002029	1.023027	25	0.0177	30	71.08	4.949	3.815	11.43234	0.410664041	1549.279
52	0.003514	1.023027	25	0.0177	30	64.26	4.308	3.713	10.82919	0.454248366	908.655
36	0.02641	1.023027	25	0.0177	30	66.07	5.395	3.794	11.30683	0.441804147	139.481
38	0.005355	1.023027	25	0.0177	30	64.55	4.392	3.745	11.01666	0.452207591	594.332
39	0.036275	1.023027	25	0.0177	30	58.07	3.902	3.712	10.82336	0.502669192	86.884

Table 2: PERMEABILITY RESULT OF SAMPLES WITH LENGTH/DIAMETER RATIO OF 1:1

	Press. P (atm)	Barometric B (atm)	Temp. (^{0}C)	Gas visc. C_p	Vol. timed (cc)	Avg. time (s)	Lgth (cm)	Diam. (cm)	Area (cm^2)	Flow rate Q (cc/s)	Perm. k (mdarcy)
53	0.001207	1.023027	25	0.0177	30	72.24	3.703	3.703	10.77094	0.404069767	2035.946
77	0.001114	1.023027	25	0.0177	30	67.04	3.706	3.706	10.7884	0.435411695	2375.200
5	0.001134	1.023027	25	0.0177	30	55.17	3.713	3.713	10.82919	0.529091898	2829.955
16	0.000888	1.023027	25	0.0177	30	67.74	3.719	3.719	10.86422	0.430912312	2938.924
43	0.001011	1.023027	25	0.0177	30	56.75	3.714	3.714	10.83503	0.514361233	3085.231
58	0.000815	1.023027	25	0.0177	30	59.17	3.711	3.711	10.81753	0.49332432	3673.991
73	0.000545	1.023027	25	0.0177	30	56.08	3.684	3.684	10.66069	0.520506419	5840.115
88	0.000864	1.023027	25	0.0177	30	65.32	3.736	3.736	10.96377	0.446876914	3118.251
8	0.000496	1.023027	25	0.0177	30	54.76	3.74	3.74	10.98726	0.533053324	6473.500
57	0.000643	1.023027	25	0.0177	30	52	3.768	3.768	11.15239	0.561346154	5219.147
61	0.000717	1.023027	25	0.0177	30	71.81	3.731	3.731	10.93444	0.406489347	3422.785
12	0.000864	1.023027	25	0.0177	30	61.85	3.74	3.74	10.98726	0.471948262	3289.673
68	0.001158	1.023027	25	0.0177	30	61.56	3.703	3.703	10.77094	0.47417154	2490.317
20	0.00079	1.023027	25	0.0177	30	64.46	3.732	3.732	10.94031	0.45283897	3459.669
6	0.001011	1.023027	25	0.0177	30	54.51	3.737	3.737	10.96964	0.535498074	3192.245
51	0.01198	1.023027	25	0.0177	30	64.57	3.781	3.781	11.22948	0.452067524	223.579
41	0.001907	1.023027	25	0.0177	30	60.3	3.708	3.708	10.80005	0.484079602	1541.164
48	0.002029	1.023027	25	0.0177	30	71.08	3.815	3.815	11.43234	0.410664041	1194.281
52	0.003514	1.023027	25	0.0177	30	64.26	3.713	3.713	10.82919	0.454248366	783.156
36	0.02641	1.023027	25	0.0177	30	66.07	3.794	3.794	11.30683	0.441804147	98.089
38	0.005355	1.023027	25	0.0177	30	64.55	3.745	3.745	11.01666	0.452207591	506.779
39	0.036275	1.023027	25	0.0177	30	58.07	3.712	3.712	10.82336	0.502669192	82.65358615

Table 3: PERMEABILITY RESULT OF SAMPLES WITH LENGTH/DIAMETER RATIO OF 0.5:1

Sample No.	Press. P (atm)	Barometric B (atm)	Temperature (^0C)	Gas viscosity C_p	volume time d (cc)	Average time (s)	Length (cm)	Diameter (cm)	Area (cm^2)	Flow rate Q (cc/s)	Perm. K (millidarcy)
53	0.001207	1.023027	25	0.0177	30	72.24	1.8515	3.703	10.77094	0.404069767	1017.973
77	0.001114	1.023027	25	0.0177	30	67.04	1.853	3.706	10.7884	0.435411695	1187.600
5	0.001134	1.023027	25	0.0177	30	55.17	1.8565	3.713	10.82919	0.529091898	1414.978
16	0.000888	1.023027	25	0.0177	30	67.74	1.8595	3.719	10.86422	0.430912312	1469.462
43	0.001011	1.023027	25	0.0177	30	56.75	1.857	3.714	10.83503	0.514361233	1542.616
58	0.000815	1.023027	25	0.0177	30	59.17	1.8555	3.711	10.81753	0.49332432	1836.995
73	0.000545	1.023027	25	0.0177	30	56.08	1.842	3.684	10.66069	0.520506419	2920.057
88	0.000864	1.023027	25	0.0177	30	65.32	1.868	3.736	10.96377	0.446876914	1559.125
8	0.000496	1.023027	25	0.0177	30	54.76	1.87	3.74	10.98726	0.533053324	3236.750
57	0.000643	1.023027	25	0.0177	30	52	1.884	3.768	11.15239	0.561346154	2609.573
61	0.000717	1.023027	25	0.0177	30	71.81	1.8655	3.731	10.93444	0.406489347	1711.393
12	0.000864	1.023027	25	0.0177	30	61.85	1.87	3.74	10.98726	0.471948262	1644.837
68	0.001158	1.023027	25	0.0177	30	61.56	1.8515	3.703	10.77094	0.47417154	1245.158
20	0.00079	1.023027	25	0.0177	30	64.46	1.866	3.732	10.94031	0.45283897	1729.834
6	0.001011	1.023027	25	0.0177	30	54.51	1.8685	3.737	10.96964	0.535498074	1596.122
51	0.01198	1.023027	25	0.0177	30	64.57	1.8905	3.781	11.22948	0.452067524	111.790
41	0.001907	1.023027	25	0.0177	30	60.3	1.854	3.708	10.80005	0.484079602	770.582
48	0.002029	1.023027	25	0.0177	30	71.08	1.9075	3.815	11.43234	0.410664041	597.141
52	0.003514	1.023027	25	0.0177	30	64.26	1.8565	3.713	10.82919	0.454248366	391.578
36	0.02641	1.023027	25	0.0177	30	66.07	1.897	3.794	11.30683	0.441804147	49.045
38	0.005355	1.023027	25	0.0177	30	64.55	1.8725	3.745	11.01666	0.452207591	253.389
39	0.036275	1.023027	25	0.0177	30	58.07	1.856	3.712	10.82336	0.502669192	41.327

TABLE 4: Porosity Values And Standard Permeability Values At Varying Length/Diameter Ratios

POROSITY	PERMEABILITY(>1:1)	PERMEABILITY(< 1:1)	PERMEABILITY (0.5:1)
29.6	3262	2035	1018
28.7	3565	2375	1188
36	4478	2829	1415
30	4364	2939	1469
27.3	3913	3085	1543
31.4	5860	3674	1837
26.4	8610	5840	2920
22.7	3703	3118	1559
24.4	7323	6473	3237
27.6	7708	5219	2610
30.1	5911	3423	1711
22.9	4767	3290	1645
25.2	4092	2490	1245
27.3	5638	3460	1730
35.9	4839	3192	1596
16.7	313	224	112
15	1792	1541	771
28.7	1549	1194	597
18.6	909	783	392
17.1	139	98	49
16.9	594	507	253
17.1	86	83	41

CROSS PLOT SHOWING PERMEABILITY AT STANDARD LENGTH AND POROSITY

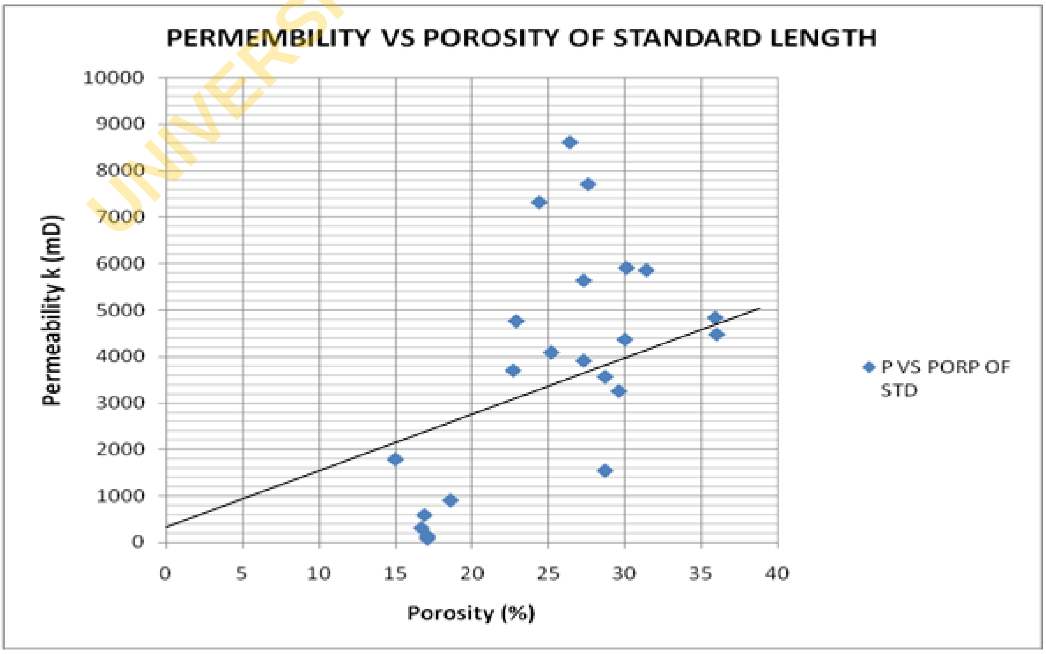

Figure 1: Standard Length and Porosity

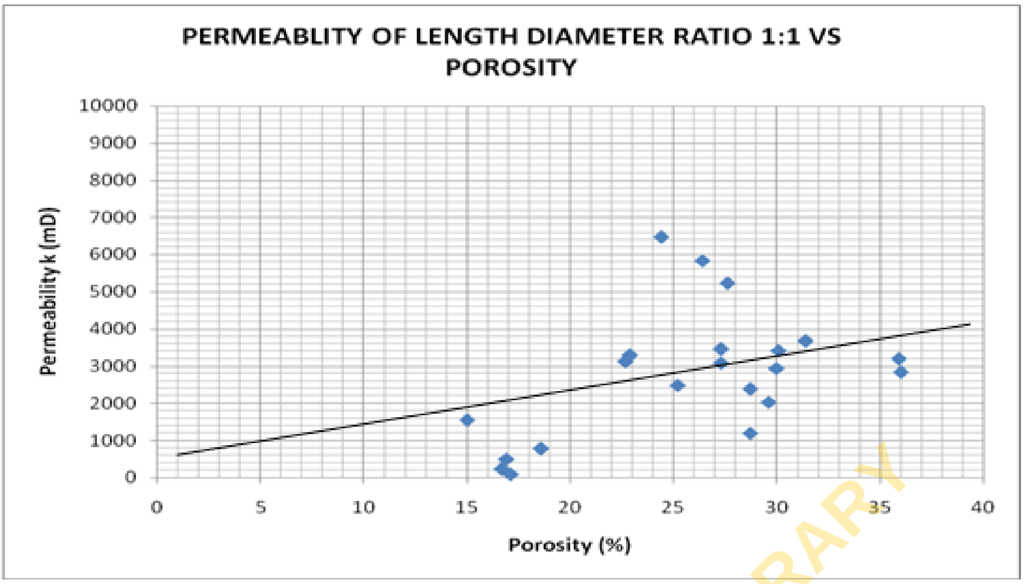

Figure 2: Length Diameter Ratio 1:1 and porosity

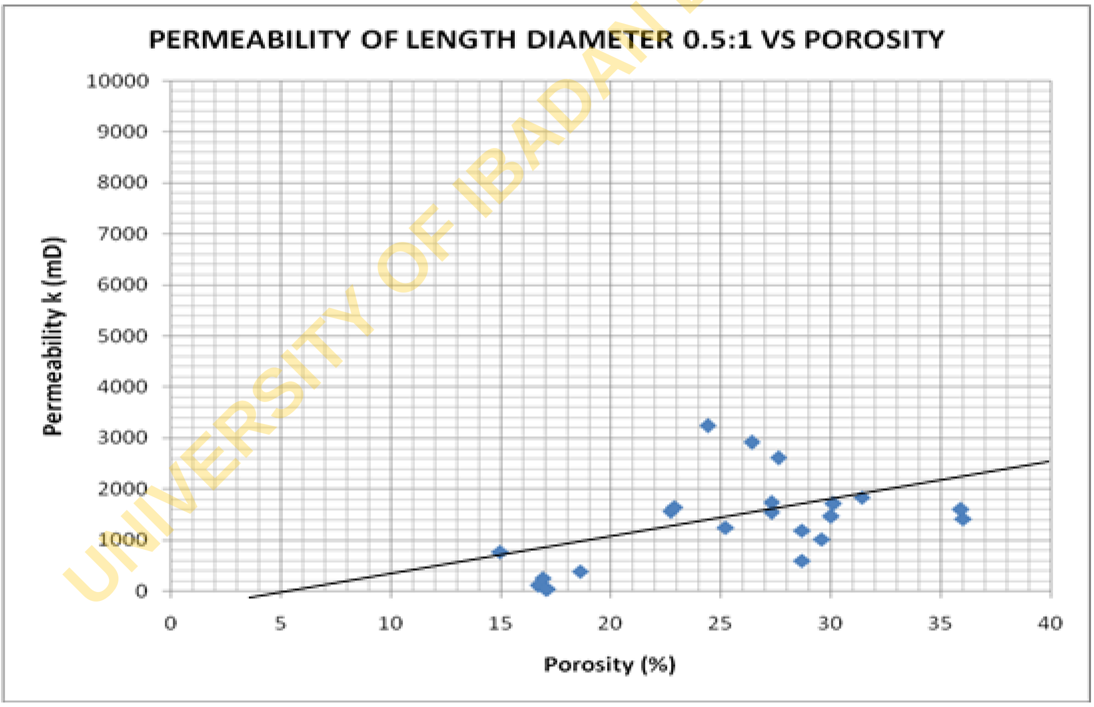

Figure 3: Length/Diameter Ratio 0.5:1 and Porosity

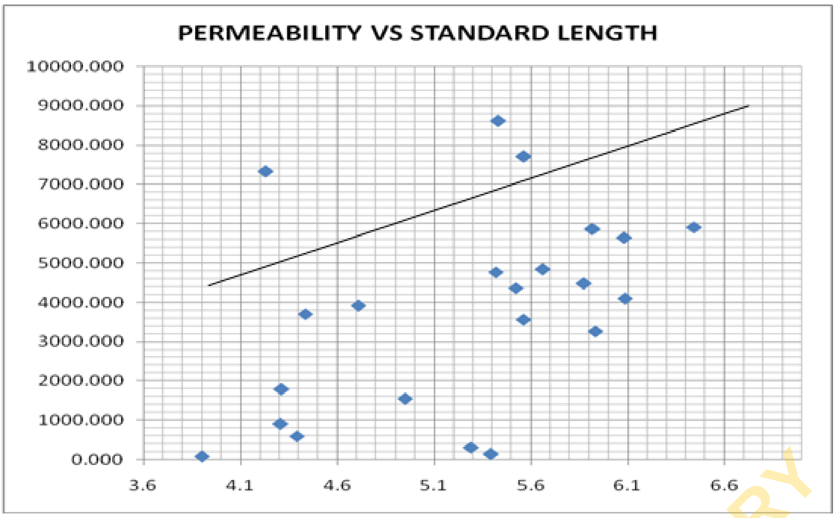

Figure 4: Permeability and Standard Length

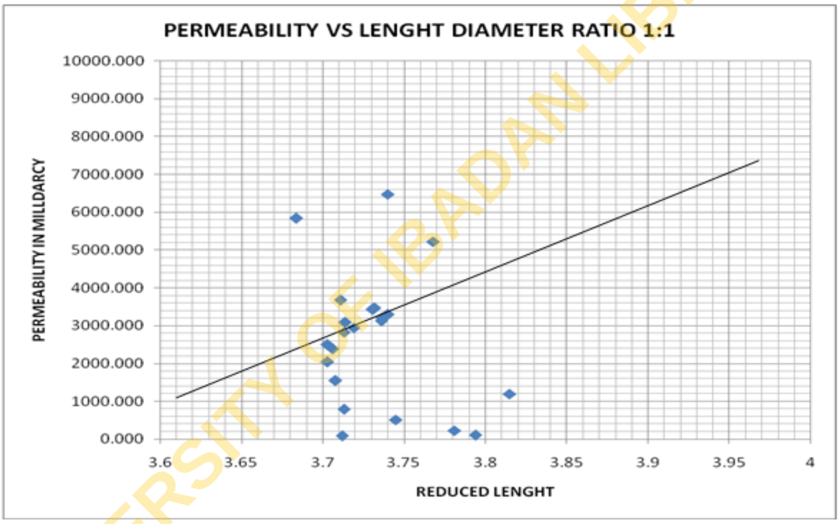

Figure 5: Permeability and Reduced Length

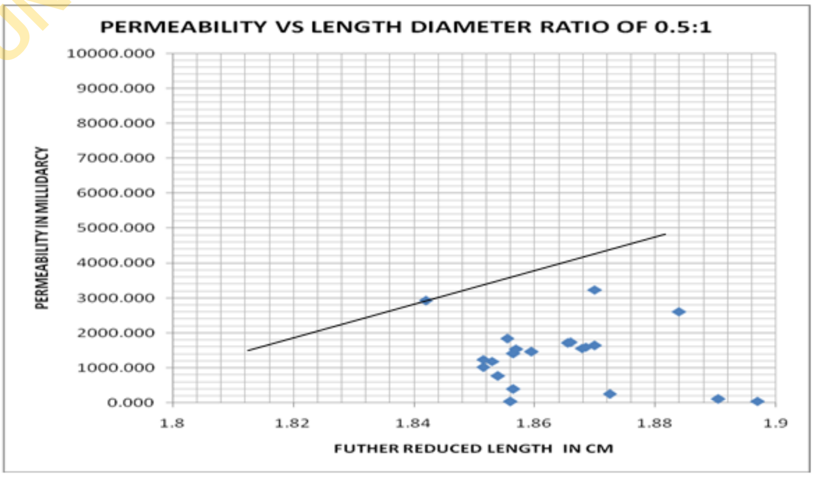

Figure 6: Permeability and Length/Diameter Ratio of 0.5:1