ORIGINAL RESEARCH ARTICLE

Comparative Study of Porosity Measurements in Shales from Kachchh and Kaladgi Basin.

Sagar Thakurdas[1], Dhanajay Meshram[2]& Bhawanisingh G. Desai[3]

[1]Department of Geology, Nowrosjee Wadia College, Pune [MS], India 411001.
[2]Department of Geology, Savitribai Phule Pune University, Pune, [MS], India.
[3]Pandit Deendayal Energy University, Gandhinagar, Gujrat, India.

Abstract:
The purpose of Core Analysis is to obtain information about the reservoir rock. This data is useful in designing Production Operations efficiently. The core analysis could provide useful data in Petrophysical and reservoir engineering, such as grain density, bulk volume, porosity and permeability values obtained from rock core plugs. These parameters, along with other Petrophysical properties, can be used in rock typing. However, a few limitations hamper the results and conclusions. The present study relates the porosity measurements of the fissile and soft shale samples from Kachchh and Kaladgi Basins.The plugging of core samples from fractured and layered shale is a challenging task. Different methodologies are applied for measuring the porosity from these two sets and these methods are presented below. It is found that the porosity values shown by the highly unconsolidated shales from Kachchh are too high whereas the Kaladgi samples show the porosity, in proximity to the expected range, of 1to2.3%. The moderately consolidated shales from Kachchh have shown porosity between the ranges from 10 to 20 %. The exaggerated porosity could be attributed to the technical difficulties encountered during the measurement process.

Key Words: ***Kachchh Basins, Kaladgi Basins.***

Introduction:

Present day energy basket is still dominated by conventional fossil fuels. However, unconventional hydrocarbon resources, including shale gas have gained significance due to its successful exploitation in North America and improved production techniques. The petrophysical studies of shale have been geared up all around the world. Typically, unconventional reservoirs of gas have low porosity and permeability when compared to the conventional reservoir rock, such as Sandstone and Carbonate.

Shale samples are predominantly dominated with clays and are usually fine-grained, laminated sediments, with grain size smaller than 4 microns. These areone of the most common sedimentary rocks and are primarily characterized by low porosities and nano-darcypermeabilities [1]. The gas occurrence within the shalesis in three different forms. It occurs either as free gas in pores, free gas in fracture soras adsorbed gas in kerogens.

This paper deals with the methodology and its implications in understanding the porosity of shales from representative outcrop samples in Kachchh basin and Kaladgi basin.

Address for correspondence:
Mr. Sagar Thakurdas,
Department of Geology,
Nowrosjee Wadia College,
Pune [MS], India : 411001
Email ID: sagarthakurdas@gmail.com

How to cite this article:
Sagar Thakurdas, Dhanajay Meshram & Bhawanisingh G. Desai. Comparative Study of Porosity Measurements in Shales from Kachchh and Kaladgi Basin.*International Journal of Current Medical and Applied sciences; 2023, 38(2), 36-42.*

Access this Article Online

Quick Response Code

Website: www.ijcmaas.com

Subject: Applied Sciences

Shale porosity is one of the most important petrophysical properties used for estimating the resources and planning production scenario of shale gas reservoir. Earlier studies haveconcluded that the porosity measurement by Gas Injection Porosimetry (GIP) is challenging due to the composite mineralogy; the results from different samples vary with contradictions [2]. The shale porosities range from 2% to 30% and are dependent on the degree of consolidation. Unconventional reservoirs, such as shale have low porosity (typically 2-10%) [3]. The purpose of the paper is to evaluate and optimize the process of shale porosity determining technique.

Sampling and Geographical LocationKachchh and Kaladgi Basin:

Outcrop shale samples were collected from two basins (a) Kachchh Basin and (b) Kaladagi Basin. Both basins show extensive development of shales.While Kachchh shale samples are more fragile and fissile the Kaladagi basin samples are thick and less fragile and fissile. Kachchh Samples were collected from the shale exposures in Western Kachchh, Near Jara and Guneri, (Figure 3A).

Kachchh basin exposes excellent exposures of the Mesozoic sediments. Stratigraphy of the Kachchh basin is given in table 1 and of Kaladgi Basin is given in figure 1B. The samples from the basin are taken from the Middle Rudramata Member of the Jhuran Formation. Middle Rudramata Member is a prominent shale memberexposed in the Kachchh basin. It is organic-rich shale with varying Total Organic Content (TOC) Values ranging from 0.2 up to 7 % (4). The Shales were deposited in the river-dominated deltaic environment [5].

Other set of samples were collected from Kaladgi basin. The Kaladgi super group of rocks are divided into lower Bagalkot and Upper Badami groups, the lower most Lokapur subgroup is the thickest and it is spread all over the basin. It is preserved inthe form of doubly plunging synclinoria [6]. The study area is located at the fringe of this syncline (Figure 1B). Thinly bedded shales and siltstones are seen in the Lokapur subgroup. These are purple ferruginous and siliceous deposits of Mud Flat [7]. The samples are taken from the Yadhalli Argillite formation. The spot represents the Yadhalli syncline exposing the sequence of Simikeri subgroup (Figure 1B). Yadhalli argillite is purple to brown colored slightly meta-morphised argillaceous rock (Figure 2C). The samples were collected from four successive sampling spots from a well exposed section (Figure 3C).

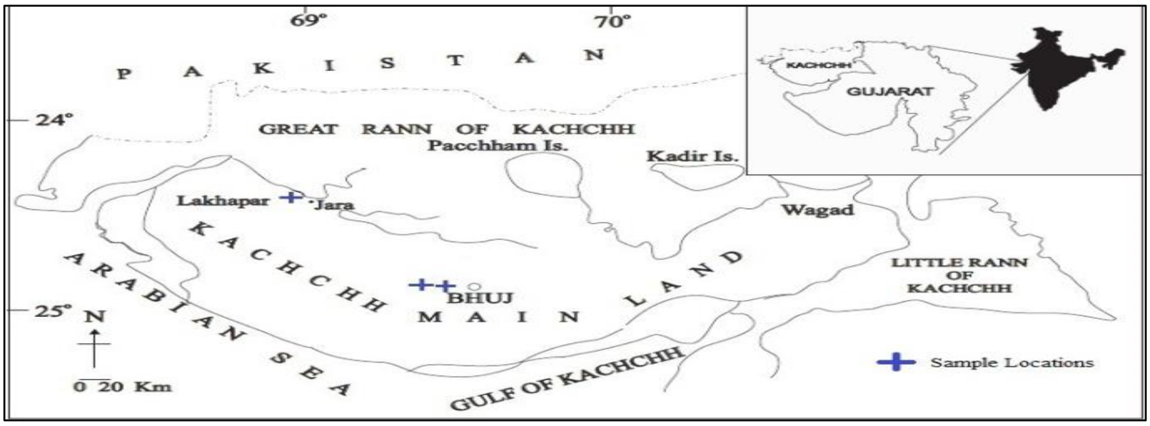

Figure 1: Location Map of Kachchh Basin [8]

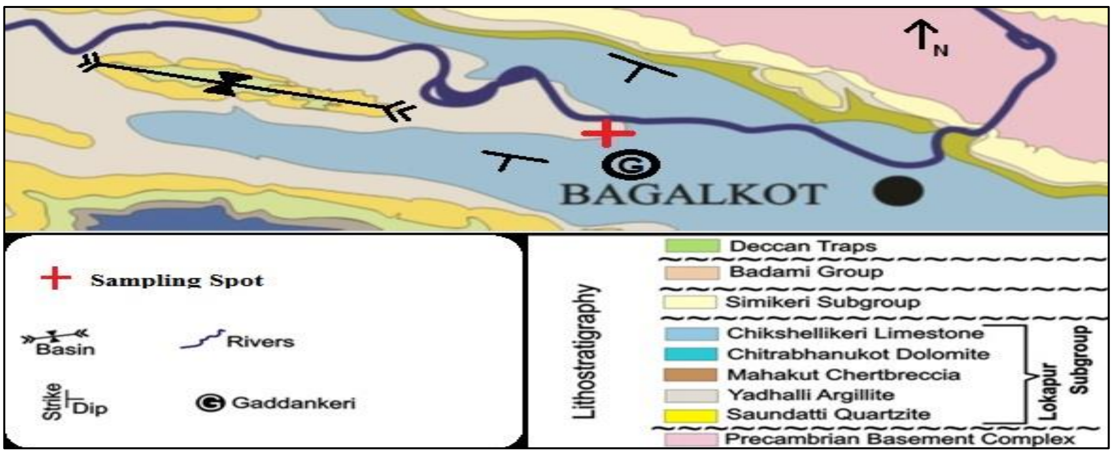

Figure 2: Location Map Kaladgi basin [9]

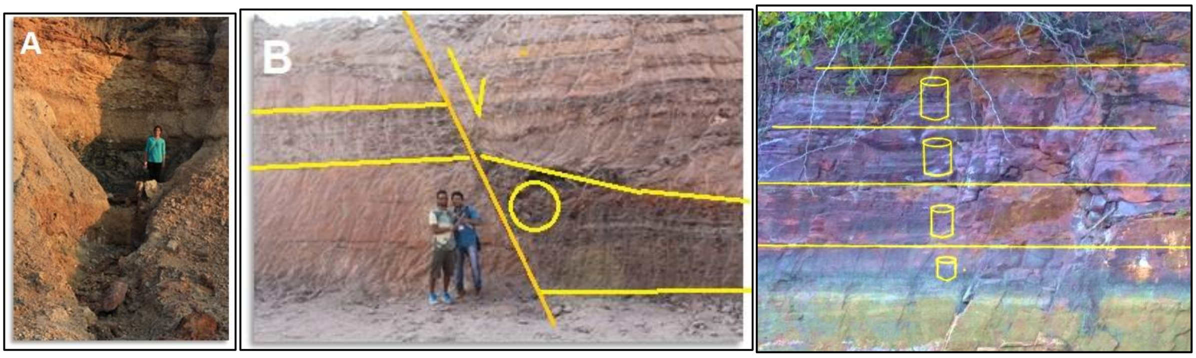

Figure 3A: Exposed section of Ratia Shale (Kachchh), B: Shale exposure on Kodki road cutting(Kachchh), C: Yadhalli section (Kaladgi)

Table 1: Mesozoic Stratigraphy of Kachchh [10]:

Age	Litho-Unit Thckness	Lithology	Environment
Kachchh Mainland			
Early Cretaceous	Bhuj Formation (400-900 m+)	**Upper Part:** Coarse grained, felspathic sandstone **Ukra Member** **Lower part:** Brown and reddish felspathic sandstone, ironstone and kaolinitic shale	Fluviatile to deltaic
Tithonian To Kimmeridhian	Jhuran Formation (375 - 850 m)	**Upper Member:** Pink and yellow sandstone with minor shale **Middle Member:** Grey shale Rudramata Shale member **Lower Member:** Shale and sandstone with calcareous bands	Infra-littoral Deltaic
Callovian to Oxfordian	Jumara Formation (300 m)	**Dosa Oolite**: Grey gypseous shale Middle member Lower Member	Sub-littoral
Upper Bathonian to Callovian	Jhurio Formation (325 m +)	Bedded white limestone Golden Oolite Limestone/Shale Limestone/Shale interbedded	Sub-littoral

Methodology:

Kachchh Basin Sample Analysis:

A total of 10 rock samples were selected from the study area (Kachchh) for the initial study. The samples consisted of shale and siltstone. The analysis was carried out at the ICS (Integrated Consultancy Services) laboratory (Alibaug). There are special issues relating to working on highly fissile and fractured shale. Due to higher fissility and presence of weaker planes, the rock splits spontaneously. Once a fissile shale core hassplit, it may be impossible to obtain desired results, while applying the conventional methods of porosity and permeability measurement.

As the collected shale samples were laminated, fissile and fractured, it was very difficult to obtain intact core plugs, from Kachchh basin samples, for the study. As against thisthe samples from Yadhalli Argillite Formation (Kaladgi basin), could produce intact core plugsdue to theircompact and massive nature. One shale sample from Kachchh was plugged successfully, and 15 other shale rock samples were collected. Their parameters such as grain density, porosity and permeability were measured. A total of 1 plug and sevenrandom samples from Kachchh were chosen for further analysis.

Unconsolidated shale samples pose unique challenges in porosity determination. In these samples, the Bulk volume measurement was carried out with the help of Archimedes Principle (Buoyancy), which requires Mercury Immersion of the samples.

These samples were soaked in methanol solvent to remove the salts and then dried to a constant weight in a conventional oven. The Grain Density, Pore Volume and Permeability measurements were then carried out on these samples.

Measurement of Grain Density:

Helium porosimeter was used to measure the grain density (Figure 4A). The helium porosimeter follows Boyle's Law ($P_1V_1=P_2V_2$). The porosimeter uses a research-grade transducer with an accuracy of 0.05% full scale. The system uses a 5 point Calibration routine for calibrated discs.Helium is introduced into a reference (V_R) chamber at about 200 psi. The stabilized pressure P_1 is noted. The pressurized helium is then allowed to expand into the sample chamber containing steel discs of known volumes, and the stabilized pressure P_2 is noted. The process is repeated with discs of varying volumes in the sample chamber. The ratio of P_1/P_2 v/s volume of discs (V_d) in the cup is plotted on a linear scale. A linear equation fits the data, the slope of the line and the intercept are automatically calculated.

After the calibration, a sample is kept in the sample chamber. Helium gas is injected in thereference chamber at pre-decided pressure, 200 psig. After 30 seconds, pressure equilibrium is achieved, and then the stabilized pressure (P_1) is recorded. The gas is then allowed to enter the sample chamber, and the resulting stabilized lower pressure (P_2) is measured. Once the grain volume is obtained, the following equation is used to calculate the grain volumes of unknown samples. The results are shown in Table 2.

Grain Density = Sample Weight (Dry) (gms) / Measured Grain Volume……………………..Eq.-I

Based on Grain Volume, porosity was calculated by following the steps given below

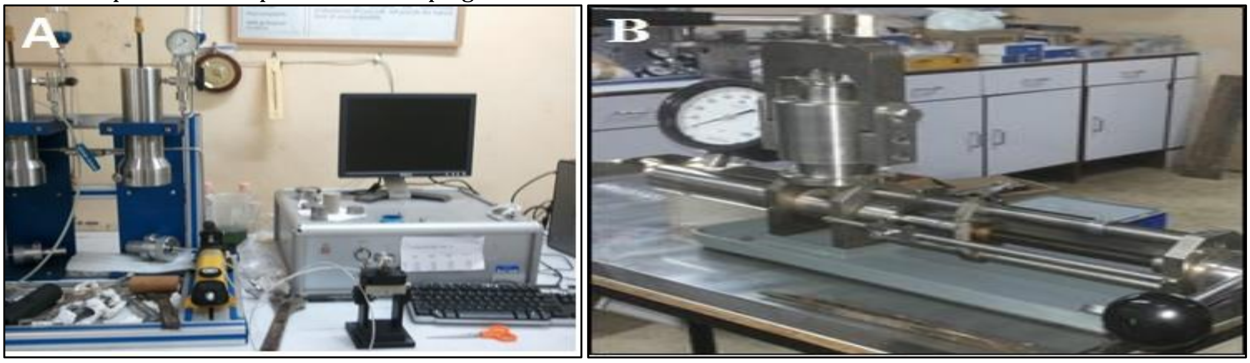

Figure 4A: Helium Porosimeter 4B: Archimedes Mercury immersionapparatus

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Measurement of Bulk Volume and Calculation of Porosity:

Since most of the samples were non cylindrical, the Bulk Volume of the sample was measured by the Archimedes Principle (Figure 4B). Samples were dipped in Mercury, and the Bulk Volume, Pore Volume and Porosity was calculated with the help of the equation II, III and IV respectively.

Measured Bulk Volume = Weight of sample in Hg / Density of Hg……………........Eq.-II

Pore Volume = Measured Bulk Volume – Grain Volume ………………..……………Eq.-III

Porosity = 100 * Pore Volume / Measured Bulk Volume ………………………………Eq.-IV

Measurement of Pore Volume and Calculation of Porosity (For the whole core Plug):

Now, for the whole core plug (Figure 5), the Bulk Volume of samples is calculated by measuring the dimensions of the samples with the help of Vernier caliper. Equation V gives bulk volume, VI gives Pore Volume and VII gives the Porosity.

Bulk Volume = (22/28) * (Diameter) 2 * Length…………………………….....………Eq.-V

Pore Volume = bulk Volume – Grain Volume …………………………………..………..Eq.-VI

Porosity = 100 * (Calculated Pore Volume) / (Bulk Volume) %……………….……Eq.-VII

Measurement of Permeability (For the whole core Plug):

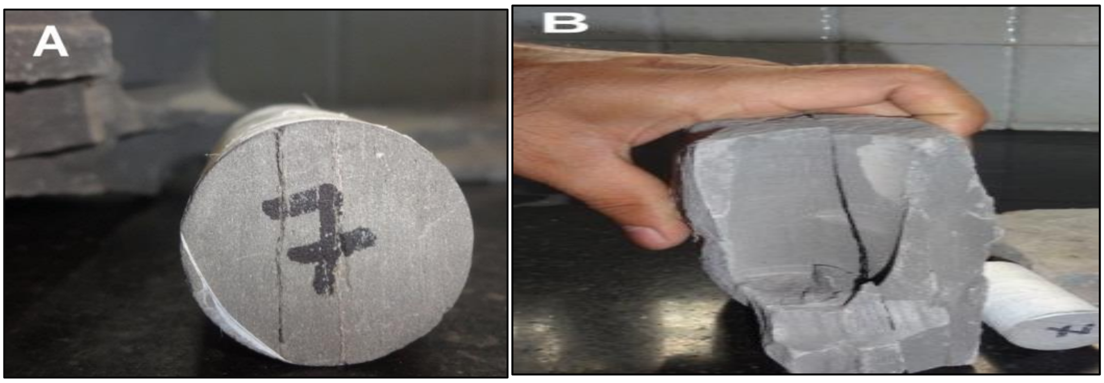

Figure 5A:A fractured core plug B.A fractured sample while retrieving in the core plug

A Steady-State Permeameteris used to measure permeability. The sample is confined under an overburden pressure of 500 psig. This pressure will hold the sample in the rubber sleeve and not allow the bypass of gas. Nitrogen gas flows at a fixed flowrate through the sample. The upstream pressure, gas flow rates and temperature, permeability can be calculated using Darcy's Equation for Compressible Fluids (Eq.-VIII).

$$Ka = (1000 \times Qm \times \mu \times L) / ((P1 - P2) \times A) \quad \text{......................................Eq.-VIII}$$

Where, Ka= Permeability to gas (not corrected for slip) [md], μ = Viscosity of gas[cp],Pa = Atmospheric Pressure [atm, absolute] or Pa= Barometric Pressure [mm Hg / 760], P1= Inlet Pressure [atm, absolute], = (Differential Pressure – Downstream Pressure) + Pa [atm, absolute], P2 = Downstream Pressure [atm, absolute],Pmean = (P1 + P2) / 2 [atm, absolute],Qm= Flow Rate of Gas at Mean Flowing Pressure[cc / sec] or Qm= (Flow – meter Value) x (Pa / Pmean)[cc / sec], L = Sample Length [cm], A = Sample Area [cm^2].

Results:
Table 2 shows the porosities of the tested samples, along with the Dry weight, Grain Density, Pore Volume and Permeability. The grain density of tested samples fall between 2.48 to 2.67 gm/cc, which is well within the expected range. Shales ideally show grain density ranging between 2.65–2.8 g/cc. Shales consist of a variety of minerals that possess different densities, based on their quantity. Apart from the technical issues related to porosity measurements, these factors also affect the total measured porosity.

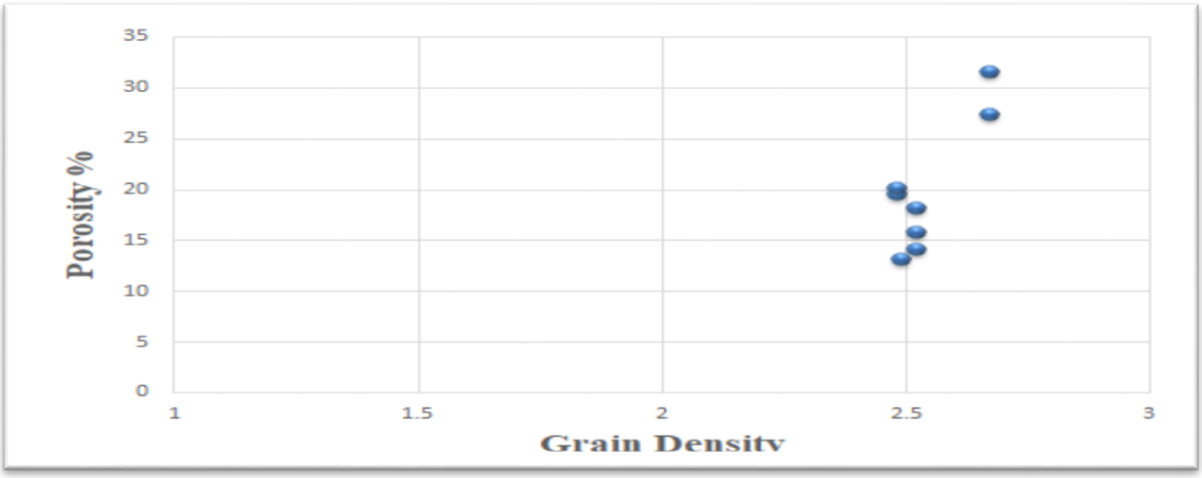

Figure 7: The plot of Gain Density vs Porosity

Table 2: Results of Porosity and Permeability Analyses (Kachchh Basin)

Sample No.	Dry Weight gms	GV Cc	GD Gms/cc	PV cc	Porosity %	Kair md
1	20.013	7.507	2.67	2.823	27.33	-
4	19.693	7.367	2.67	3.395	31.55	-
5	19.616	7.771	2.52	1.270	14.04	-
6	37.835	15.023	2.52	3.313	18.07	-
7	51.759	20.519	2.52	3.828	15.72	2.604
8	28.062	11.254	2.49	1.693	13.08	-
9	10.572	4.266	2.48	1.033	19.50	-
10	10.748	4.334	2.48	1.084	20.01	-

The plot of Grain Density Vs Porosity shows that the porosity of samples 5,6,7,8,9 and 10 are in the range of 10 to 20%. The two sample (1 and 4), which show very porosity were highly unconsolidated and fractured.

Kaladgi Basin Sample Analysis:

A total of 11 samples were selected for porosity measurement. The Yadhalli Argillite is massive and compact, as a result perfectly cylindrical core plugs were obtained. Barne's method is used to determine the Effective porosity at STP. Barne's method is based on the adsorption of fluid (Di-ionized water) in pores of the core plug until its complete saturation [11]. This Water Immersion Porosity (WIP) technique is applied in this case.

The bulk volume of core plugs is measured with the help of vernier caliper. The heated and dried samples are weighed. The core plugs are then placed in a container containing Di-Ionized water, with water level being 1 inch above the core samples. The Di-ionized water has greater rate of penetration and helps in complete saturation of pore spaces. The core plugs are allowed to saturate for 24 hours. Afterwards, the samples are removed from the container and excess water from the surface is gently wiped off with cotton. Wet samples are then weighed. Following equations are used to find the porosity.Barne's method is an important technique often used in petroleum industry to understand oil and gas flow of geological formations [11].

Bulk Volume = $\pi r^2 L$……………………………………………………………………..….Eq.-IX

Weight of Soaked Water = Weight of soaked sample – Weight of dry sample……………..Eq.-X

Since, Weight = Mass * Acceleration due to Gravity

Mass of Soaked Water = Weight of Soaked Water/ Acceleration due to Gravity…….…….Eq.-XI

Volume of water soaked=Mass of Soaked Water/ Density of Water at 4^0C………......... Eq.-XII

(Density of distilled water at 4 degree Celsius is 1 gm/cc)

Now, Volume of water soaked is the interconnected pore volume.

Finally,

Effective porosity = Interconnected pore volume/Bulk volume of sample……………..…. Eq.-XIII

In spite of the possible lacunae of this technique, it has been found more reliable method for mudrock (shale) than GRI and MIP methods. The simple technique makes it more preferred for routine core total porosity measurements [12].

A summary of results is shown in Table 3 with values of core plugs ranging between 1.17 to 2.21% .These porosity values are characteristic of shale. The error during the manual measurements, both vernier caliper and weighing scale, is expected. These instruments usually have inherent faults or errors associated with them. These errors must be taken into consideration while analyzing the data. For the vernier caliper the expected error is 0.05 mm and for the weighing machine it is 0.005 grams. Taking this into consideration, the relative maximum and minimum porosity for these samples would range between 1.12 to 2.26%.

Table 3: Water Immersion Porosity for the selected 11 samples.

Sample	Diameter (Inches)	Length (Inches)	Bulk Volume (CC)	Dry Weight (gm)	Wet Weight (gm)	Porosity Percentage %
A	2.446667	5.443333	25.57904	52.612	57.346	**1.886579**
B	2.32	4.26	17.99928	40.626	44.443	**2.161712**
D	2.418	3.111667	14.28155	30.398	33.189	**1.99212**
E	2.323333	6.12	25.93248	59.129	64.759	**2.213071**
F	2.336667	4.845	20.7662	48.12167	52.489	**2.14383**
J	2.336667	4.56	19.54466	44.17767	48.224	**2.110399**
K	2.326667	3.243333	13.78255	30.99767	33.916	**2.158422**
L	2.37	5.146667	22.69302	50.38867	54.908	**2.030079**
O	2.39	5.213333	23.37658	49.381	53.821	**1.936123**
P	2.316667	5.536667	23.32626	54.69167	59.678	**2.17905**
U	2.316667	5.293333	22.30109	51.281	56.131	**2.216903**

Conclusion:

Following conclusions were drawn after reviewing the difficulties encountered during the analyses of the shale rock samples:

1. Grain volume measurements and subsequently the Porosity measurement can be carried out, with Helium porosimeter, when the rock samples are non-cylindrical, with intergranular porosity.
2. Possible reasons for the exaggerated porosity values in Kachchh shale include:
   i. It could also be due to the adsorption of the Helium gas on the rock matrix and organic matter.
   ii. The air trapped in and around the sample could have resulted in the higher value of bulk volume.
   iii. The mercury immersion gives unrealistic results if the shale samples are fractured. The measured bulk volume is higher due to the penetration of Mercury in highly

fractured and porous samples. However, this method is less time-consuming.

3. WIP method was utilized for porosity measurement of 11 core plugs from Kaladgi Basin.
   The porosity values of Kaladgi shales/Argillites range between 1.17 to 2.21% and that of Kachchh Basin between 10 to 20%. This difference in porosityis slightly influenced by the techniques adopted as well as the geological considerations have major role.
4. The results indicate that the Porosity evaluated for samples from two locations is influenced by their Geological and stratigraphic positions, depositional environments, post depositional changes and compaction of formation which has effects on properties such as size, shape, and arrangement of particle grains and pores.
5. The Yadhalli Argillite is Meso-proterozoic, slightly metamorphosed and massive in nature whereas, Rudramata shale member is Mesozoic deltaic deposit with less relatively low compaction and high fissilty.

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Conflict of interest: *None declared*
Source of funding: *None declared*