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Validation of lab derived petrophysical parameters for core segments

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Abstract

Cores are true representation of the characteristics, potential to store hydrocarbon and lithology of the reservoir. Since, availability of cores is limited to selected wells only, drill cuttings are convenient substitute for core plugs to assess the reservoir parameters as drill cuttings are collected throughout the well depth. The present study aims at establishing a technique of determining porosity of irregular shaped core segments/drill cuttings where there is no core and to establish correlation between porosity determined at different sizes of core plug. Basic petrophysical studies have been carried out on core plugs and core segments to establish correlation between porosity determined at different sizes of core pieces. The porosity of the plug samples was determined by Helium Porosimeter. The plugs have been then disintegrated progressively to smaller sizes till 1-5mm (drill cuttings size) approx. to replicate cuttings. The porosity values for core segments corresponding to the drill cutting size were determined by three different methods, i.e. Helium Porosimeter, Density Method and Mercury Injection Porosimeter and compared.

Introduction

A petroleum reservoir is a subsurface pool of hydrocarbons contained in porous or fractured rock formation. Both crude oil and natural gas occur naturally in subsurface deposits. Reservoir Rocks are the rocks that have ability to store hydrocarbon inside its pores. Reservoir rocks are dominantly sedimentary (sandstones and carbonates). The fundamental properties of a reservoir rock are its porosity and permeability. Both, porosity and permeability are geometric properties of rock and both are the result of its lithologic character.

Petrophysical studies are predominantly carried out on core plugs. Core plugs are collected through plugging of the cores collected from the drilled wells. Core plugs diameter vary from 1 inch to 1.5 inch. Drill cuttings are convenient substitute for core plugs to assess the reservoir parameters as drill cuttings are collected throughout the well depth. Petrophysical measurements on drill cuttings have an economic appeal especially in unconventional formation evaluation. Drill cuttings are readily available, a byproduct of drilling, and can potentially provide a variety of reservoir quality parameters, such as total organic carbon, porosity, mineralogy, thermal maturity, pore structure and habit, mechanical elastic properties, etc. The determination of porosity using drill cuttings can provide a more spatially detailed representation of a formation. The conventional laboratory method for determining porosity of core plugs is Helium Porosimetry. However, mercury injection porosimetry data produced on drill cuttings can be used for evaluating reservoir characteristics such as porosity and permeability and can be effectively utilized as a powerful tool for petrophysical evaluation on formation rocks through cuttings as well as irregular core pieces (P K Nag et al, 2018). Another method for determining porosity is density method, where relative density and bulk volume are determined manually, which are further used in calculation of porosity.

Figure 1. Conventional core plugs of various size

Figure 2. Drill cuttings core plugs of various size

Experimental

The core plugs were cut from different cores of the wells of Cauvery basin, using the core cutting machine at core house, Neravy complex, Karaikal. These core plugs were thoroughly washed with water and dried in the oven at 80 – 90°C. These plugs were soxhlated using toluene for completion of 4 cycles and are dried in the hot air oven for 4 hours and then preserved in desiccators. The length and diameter of these cylindrical core plugs were measured using the Vernier caliper to determine their bulk volume. The weights of the dry plugs were also measured to determine their grain density. The porosity of the core plugs was determined using three techniques i.e. Helium Porosimeter[1], Density bottle Method[2] and Mercury Injection Porosimeter[3]. The samples have been disintegrated progressively to smaller sizes till 1-5mm approx. Porosity experiments (Helium, Density and Mercury injection methods) have been performed on the samples.

Porosity and grain density from Helium Porosimeter:

Grain volume of these cylindrical core plugs was determined using Helium Porosimeter (Twardowski Kazimierz et al., 2004). The experimentally measured length and diameter of the core plugs using Vernier Caliper were fed into the computer which will in turn calculate the bulk volume. Porosity of the core plugs were then determined using these parameters.

$$\text{Porosity (\%)} = (\text{Bulk volume} - \text{Grain volume}) * 100 / \text{Bulk volume}$$

Grain density of the core plugs were also displayed from the input values of weight of the plugs and experimentally determined grain volume.

$$\text{Grain density} = \text{Wt. of the plug} / \text{Grain volume}$$

Porosity and grain density from Density bottle Method:

By Density bottle method, we determine relative density of core sample. Relative density, or specific gravity, is the ratio of the density of a substance to the density of a given reference material. The reference material employed in the current study are water and kerosene. For calculating the density, the samples are crushed into fine powder and dried in a hot air oven.

$$\text{Grain Density} = \frac{(W_4-W_1)\,(W_3-W_1)}{[(W_3-W_1) - (W_5-W_4)]\,(W_2-W_1)}$$

Where;
W_1 = Weight of empty bottle
W_2 = Weight of bottle filled water
W_3 = Weight of bottle filled with kerosene
W_4 = Weight of bottle containing known quantity of sample
W_5 = Weight of bottle containing known quantity of sample and filled with kerosene

Porosity and grain density from Mercury Injection Porosimeter:

Mercury porosimetry technique is used for probing of pore structure of cores and cuttings samples for characterization of reservoir. In high pressure mercury injection porosimetry, mercury is injected into the pores of rock samples at incrementally higher pressure. Mercury being a non-wetting fluid needs positive capillary pressure for intrusion in the pores (E W Washburn, 1921). The pressure required to be applied depends on the pore throat diameter and is controlled by the famous Washburn equation:

$$D = \frac{4\gamma \cos\theta}{P}$$

D = Pore diameter
θ= contact angle and
γ= interfacial tension for mercury and solid surface.

Results & Discussion

Table 1. Details of plugs used in sample analysis

Well No.	CC No.	Plug No.	Core interval (m)	Depth (m)
A	CC-2	1	4184.00-4193.00	4187.30
A	CC-2	2	4184.00-4193.00	4190.10
A	CC-2	3	4184.00-4193.00	4191.20
B	CC-1	4	4622.00-4631.00	4623.50
B	CC-1	5	4622.00-4631.00	4624.40
B	CC-1	6	4622.00-4631.00	4624.60
C	CC-1	7	3414.50-3423.00	3420.49
D	CC-1	8	1977.00-1985.89	1983.58

Images of plugs and core segments

The images of the core plugs and their respective core segments of different sizes are shown from Fig 3– Fig 10. The porosity values of the core plugs 1- 8 at three different sizes are given from Table 2 – table 9. The porosity values depicts an increasing trend as the size of the core sample decreases. The porosity values for cuttings size core segments show an increase of 3-4% porosity as compared to the porosity value for the plug shaped samples.

Figure 3. Plug 1

Figure 4. Plug 2

Figure 5. Plug 3

Figure 6. Plug 4

Figure 7. Plug 5

Figure 8. Plug 6

Figure 9. Plug 7

Figure 10. Plug 8

Porosity values of the plugs at different sizes determined by He Porosimeter

Table 2: Porosity values of the Plug 1 at different sizes

Plug 1		
Grain Density (g/cc)	Porosity (Fraction)	Parts
2.7	0.1167	1
2.75	0.1315	10
2.8	0.1866	Cutting size

Table 3: Porosity values of the Plug 2 at different sizes

Plug 2		
Grain Density (g/cc)	Porosity (Fraction)	Parts
2.74	0.1241	1
2.77	0.1448	10
2.72	0.1510	Cutting size

Table 4: Porosity values of the Plug 3 at different sizes

Plug 3		
Grain Density (g/cc)	Porosity (Fraction)	Parts
2.72	0.1093	1
2.76	0.1098	11
2.79	0.1362	Cutting size

Table 5: Porosity values of the Plug 4 at different sizes

Plug 4		
Grain Density (g/cc)	Porosity (Fraction)	Parts
2.73	0.0952	1
2.78	0.1122	11
2.77	0.1173	Cutting size

Table 6: Porosity values of the Plug 5 at different sizes

Plug 5		
Grain Density (g/cc)	Porosity (Fraction)	Parts
2.73	0.0770	1
2.73	0.0892	14
2.75	0.1111	Cutting size

Table 7: Porosity values of the Plug 6 at different sizes

Plug 6		
Grain Density (g/cc)	Porosity (Fraction)	Parts
2.67	0.1251	1
2.73	0.1510	9
2.75	0.1613	Cutting size

Table 8: Porosity values of the Plug 7 at different sizes

Plug 7		
Grain Density (g/cc)	Porosity (Fraction)	Parts
2.72	0.1525	1
2.78	0.1645	12
2.79	0.1938	Cutting size

Table 9: Porosity values of the Plug 8 at different sizes

Plug 8		
Grain Density (g/cc)	Porosity (Fraction)	Parts
2.76	0.0456	1
2.77	0.0581	10
2.75	0.0809	Cutting size

Graphical representation of variation of porosity values determined by He porosimeter with decrease in sample size

The graphical representation of the variation of porosity values of core plugs 1- 8 and their respective core segments are given from Fig 11- Fig 18. The graphical representation evidently shows gradual increase the porosity value as the size of the core sample decreases.

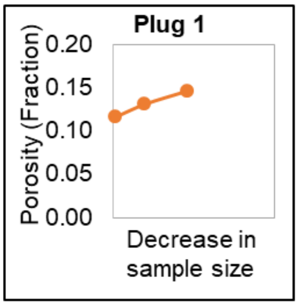

Figure 11. Variation of Φ with decrease in sample size for Plug 1

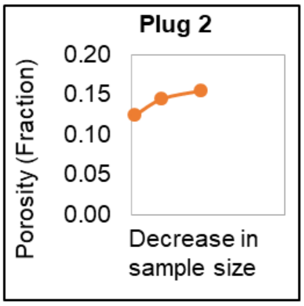

Figure 12. Variation of Φ with decrease in sample size for Plug 2

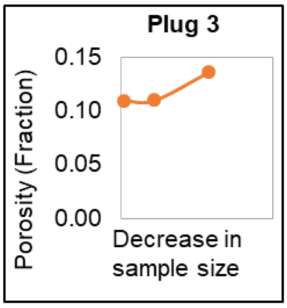

Figure 13. Variation of Φ with decrease in sample size for Plug 3

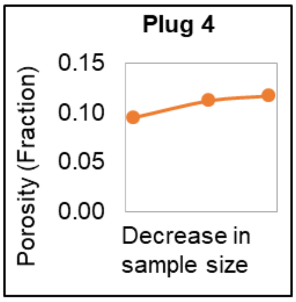

Figure 14. Variation of Φ with decrease in sample size for Plug 4

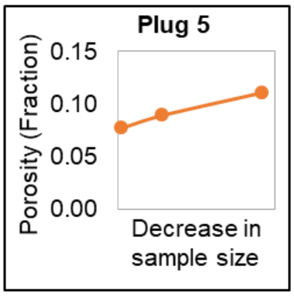

Figure 15. Variation of Φ with decrease in sample size for Plug 5

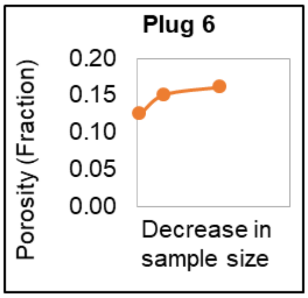

Figure 16. Variation of Φ with decrease in sample size for Plug 6

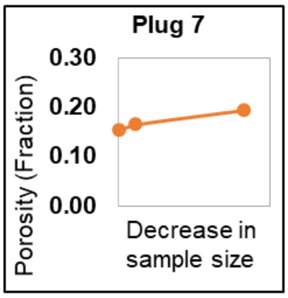

Figure 17. Variation of Φ with decrease in sample size for Plug 7

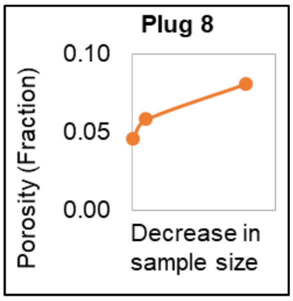

Figure 18. Variation of Φ with decrease in sample size for Plug 8

Comparison of porosity values of the core plugs and core segments

The comparison of the porosity values determined by three method i.e. He Porosimetry, Mercury Injection Porosimetry and Density Method are given in Table 10. From the porosity values obtained by the respective three methods, it is evident that there is positive correlation between the values. However, the porosity values given by Density method and Mercury Injection Porosimetry are comparable.

Table 10: Comparison of porosity values

Plug No.	Plugs (He)	Core segments		
		ϕ (He)	ϕ (Density Method)	ϕ (MIP)
1	0.1167	0.1866	0.1667	0.1618
2	0.1241	0.1510	0.1340	0.1263
3	0.1093	0.1362	0.0804	0.0899
4	0.0953	0.1173	0.0550	0.0618
5	0.0768	0.1111	0.0920	0.0733
6	0.1251	0.1613	0.1209	0.1287
7	0.1761	0.1937	0.1453	0.1631
8	0.0801	0.0810	0.0313	0.0490

Graphical representation of comparison of porosity values of the core plugs and core segments

The correlation of the porosities obtained by three different methods have been graphically represented in Fig 19, 20 and 21. The porosity values obtained by Mercury Injection Porosimeter and Density Method show maximum correlation between the values.

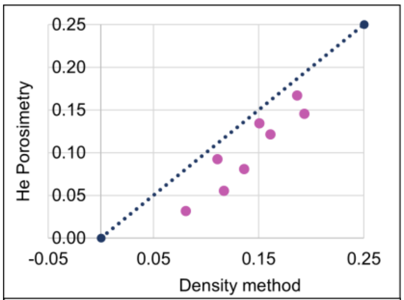

Fig 19: Correlation between porosity values determined from He Porosimetry and Density Method

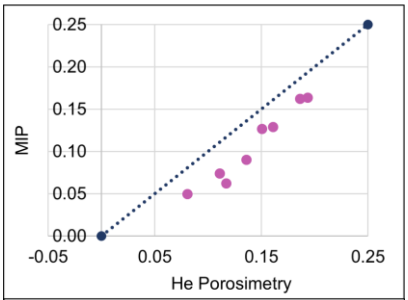

Fig 20: Correlation between porosity values determined from He Porosimetry and Mercury Injection Porosimetry (MIP)

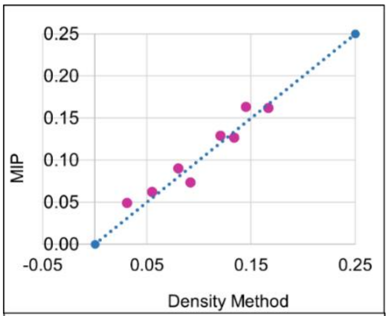

Fig 21: Correlation between porosity values determined from Mercury Injection Porosimetry (MIP) and Density Method

Conclusions

The porosity of the core samples varies along with the core sample size variation. The ϕ increases as the size of the sample decreases. The porosity data obtained by the three methods i.e. Helium Porosimetry, Density Method and Mercury Injection Porosimetry are quite comparable. However, porosity for core segments determined by density method and mercury injection method show maximum correlation. Hence, this study successfully establishes a method to validate the basic petrophysical studies for irregular core pieces & cuttings samples and both Mercury Injection Porosimetry and density method are reliable technique for porosity determination of drill cuttings.

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Statement

The views expressed in this paper are that of the authors only. They do not purport to reflect the opinions or views of ONGC.

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