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Reservoir characteristics through petrophysical studies on cuttings

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Key words
Capillary Pressure, Mercury Injection Porosimetry, Reservoir characteristics, Pore distribution.

Abstract

High-pressure mercury porosimetry has been carried out on conventional core plugs, irregular samples as well as drill cuttings to evaluate porosity, pore size / pore volume distribution. Permeability values have been estimated from pore distribution data using three different permeability models. The porosity and estimated permeability from mercury injection porosimetry experiment are in good agreement with experimentally determined porosity and permeability of cores plugs. The porosity and permeability data of drill cuttings' reveal encouraging result in evaluation of reservoir characteristics through petrophysical studies on cuttings.

Introduction:

Mercury porosimetry technique is used for probing of pore structure of cores and cuttings samples for characterization of reservoir. The high surface tension and non-wetting property of Mercury uniquely qualifies it for use in probing pore space.

A typical mercury intrusion porosimetry test involves placing a sample into a container, evacuation to remove gases and vapours (usually water) and, subsequently, allowing mercury to fill the container. This creates an environment consisting of a solid, a non-wetting liquid (mercury), and mercury vapour. 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. The pressure required to be applied depends on the pore throat diameter and is controlled by the famous Washburn equation (Reference -1),

$$D = 4\gamma \cos\theta \; P$$

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

The pressure at which mercury starts entering in the pores is termed as threshold pressure or entry pressure (P_C) (Reference-2). The pore size Lc, corresponding to the this entry pressure is characteristic pore size (Reference 2 & 3)
Methods that are intimately related with mercury injection capillary pressure studies are employed to estimate three forms of permeability: (a) from electrical conductivity (b) from hydraulic conductivity and (c) from tortuosity (Reference: 3, 4, 5 and 6).
In the present study, permeability from hydraulic conductivity is estimated.

a) Permeability from electrical conductivity:

$$K_e = (1/226)\, L_c^2\, (\sigma/ \sigma_0) \text{ ----- } (1)$$

$$\sigma/ \sigma_0 = (L_e/L_c)^* \varnothing * S(L_e)$$

- σ = conductivity of rocks
- σ_0 = conductivity of pore water
- Le = Pore dia that corresponds to maximum value of Cum Vol * Pore Dia
- S_{Le} = Saturation of mercury at pressure corresponding to Le
- Ø = Porosity

b) Permeability from Hydraulic conductivity:

$$K_h = (1/89)\, L_h^2\, (L_h/L_c)^* \, Ø * S(L_h) \text{ -----(2)}$$

- L_h = pore dia that corresponds to maximum value of (Cum Vol) *(Pore Diameter–Lc)^3
- S_{Lh} = Saturation of mercury at pressure corresponding to L_h
- Ø = Porosity

c) Permeability from Tortuosity:

$$K\Gamma = (Øi*(D_{med})2)/(16*\Gamma) \text{ ----- (3)}$$

$$\Gamma = \text{Tortuosity} = (2.23\text{-}1.13*PV*\rho b)\,\{0.92*4/S*\Sigma\,(dV//Dav\}^2$$

- D_{med} = Median pore diameter
- ρb = Bulk density of specimen
- PV pore volume per gm of specimen
- S= Surface area per gm
- dV = incremental vol between two consecutive pressures
- Dav = Average diameter corresponding to the two pressures.

Method

Core, drill cuttings and other irregular shaped rock samples were cleaned by Soxhlation with toluene and dried in air oven at 80°C. Bulk volume and Helium porosity was measured by standard Helium Porosimeter. Permeability of regular plug shaped sample was determined by Gas Permeameter.

The samples were subjected to high pressure mercury porosimetry studies using Automated Mercury Injection Porosimeter (MIP) whereby a measured amount of sample was taken in a small sample cup and pressurized incrementally up to 30,000 psi. The volume injected was recorded at each pressure step. Percentage of pore volume intruded at each step, pore diameter, cumulative volume, distribution function (dV/dLogP). Median pore diameter was determined from pore diameter corresponding to 50% of pore volume and total surface are, S was determined from the area under PV curve. Characteristic Pore size L_c, L_e and L_h, were evaluated as described in the previous section. The porosity was determined from the ultimate pore volume intruded at maximum pressure (usually 30,000 PSI). Three different permeability values were estimated from the equation 1, 2 and 3 as described above.

Results and discussion

Evaluated porosity values by Helium Porosimeter and Mercury Injection Porosimetry for the plug samples have been given in the Table1. The values are comparable. The permeability values experimentally determined for the regular shaped plugs are compared with the estimated values from mercury injection porosimetry. The values agree, reasonably well amongst the experimentally determined K_h.

In the same way, porosity and permeability values drill cuttings are tabulated in Table 2. In these cases permeability cannot be experimentally determined as it requires regular and uniform shape (cylindrical or rectangular). However porosity has been determined by Helium porosimeter as well as mercury injection porosimetry. The data show that there is fair agreement in porosity values from both the methods. Permeability from hydraulic porel conductivity has been determined by mercury injection porosimetry. Given the fact that there are fair agreement both in porosity and permeability values between experimental and estimated values for plugs samples, the K_h values for drill cuttings closely represent the 'true' reservoir porosity and permeability. This is specially advantageous in the reservoirs where there is no cores. Usually drill cuttings are always available throughout the drilled depths. This method is also useful for highly shaly/ laminated and fragile cores which causes difficulty in plugging.

Conclusion:

The mercury injection porosimetry data produced on drill cuttings can be used for evaluating reservoir characteristics such as porosity and permeability. The estimated permeability based on hydraulic conductivity (K_h) are expected to give fairly close to air permeability of the reservoir measured in the lab and can be highly useful for reservoir characterization where there is no core. This innovative method developed on Mercury injection porosimetry, can be effectively utilized as a powerful tool for petrophysical evaluation on formation rocks through cuttings as well as irregular core pieces especially in shale, which was not possible earlier.

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Table-1 Porosity and Permeability of Plugs

Sample ID	Well No.	Depth (m)	Porosity (He Porosimeter)	Permeability (mD)	Porosity (MIP)	K_H (MIP)
P1	A	3355.10	0.1371	7.805	0.1123	3.104
P2	B	1393.21	0.1312	0.200	0.1365	0.051
P3	C	2170.74	0.1442	1.003	0.1249	1.122
P4	C	2171.58	0.3796	304.247	0.3127	103.053
P5	C	2173.25	0.3099	92.891	0.2580	58.314
P6	C	2174.15	0.3141	199.321	0.2722	145.812
P7	C	2176.48	0.2058	2.384	14.37	0.617
P8	C	2340.42	0.1989	0.136	0.2001	0.302
P9	C	2341.37	0.2122	0.085	0.1807	0.034
P10	D	1946.26	0.2381	1.736	0.2112	1.206
P11	D	1947.34	0.0843	0.028	0.1301	0.274
P12	D	1948.11	0.2584	13.431	0.2041	11.773
P13	D	1949.39	0.2418	4.705	0.1822	2.482
P14	E	2165.53	0.2793	5.281	0.2274	3.332
P15	E	2166.60	0.2484	9.325	0.1921	8.613
P16	E	2168.60	0.1985	3.072	0.1621	1.244
P17	E	2171.15	0.2067	0.959	0.1640	0.263

Table-2 Porosity and Permeability of Cuttings

Sample ID	Well No.	Depth (m)	Porosity (He Porosimeter)	Porosity (MIP)	K_H (MIP)
C1	F	1595-1600	0.1838	0.1858	0.660
C2	F	1875-1880	0.1782	0.2158	0.919
C3	F	1905-1910	0.1961	0.1646	0.304
C4	F	1915-1920	0.2132	0.2565	0.103

C5	G	1935-1940	0.2196	0.2300	0.624
C6	H	3970-3975	0.3062	0.2989	4.032
C7	H	3995-4000	0.2353	0.2420	0.359

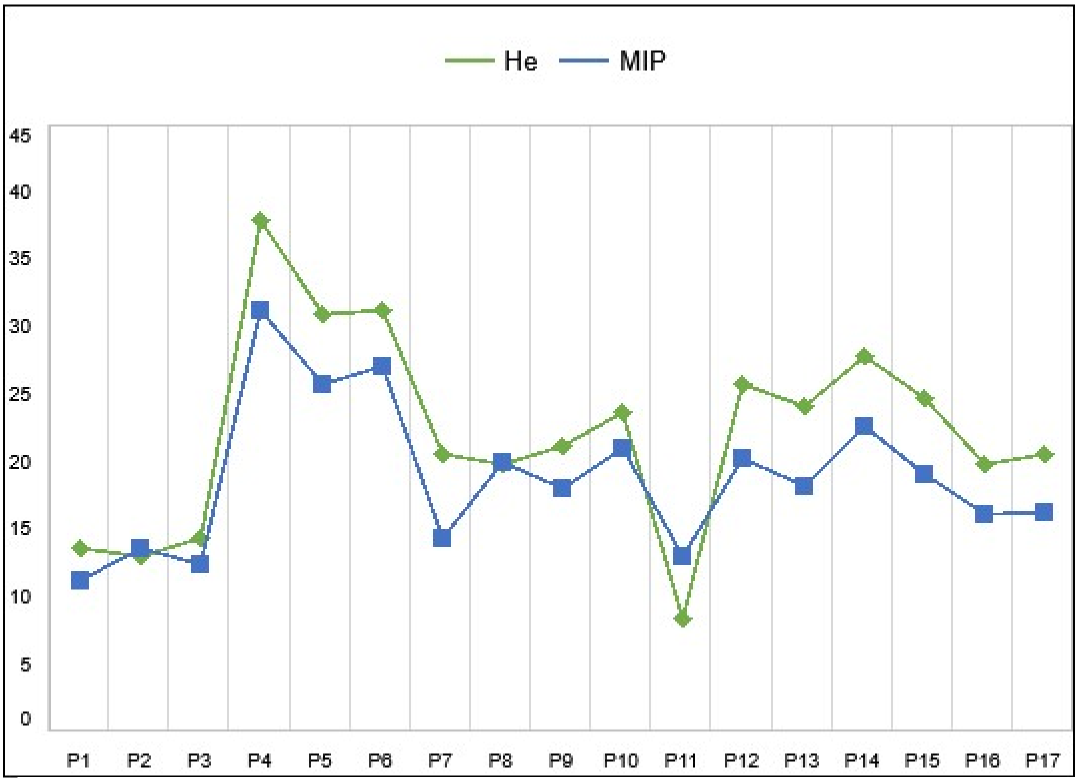

Fig 1: Comparison of Porosity of plugs by He Porosimeter and MIP

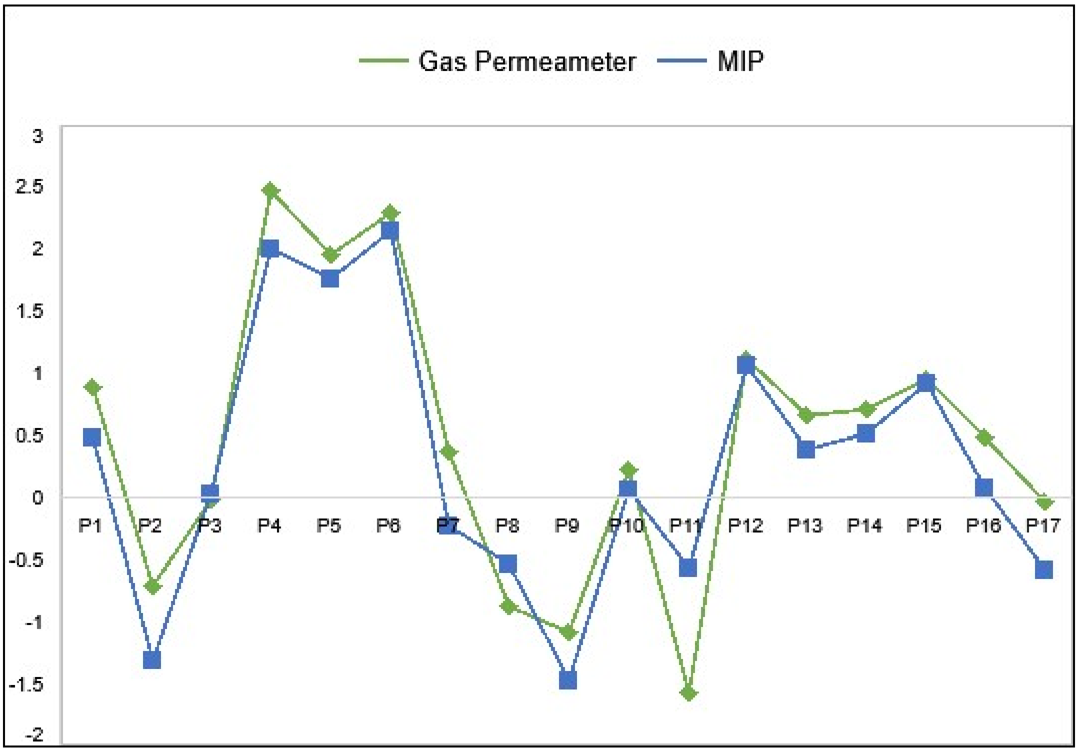

Fig 2: Experimental permeability of plugs by Gas Permeameter and estimated permeability from hydraulic conductivity

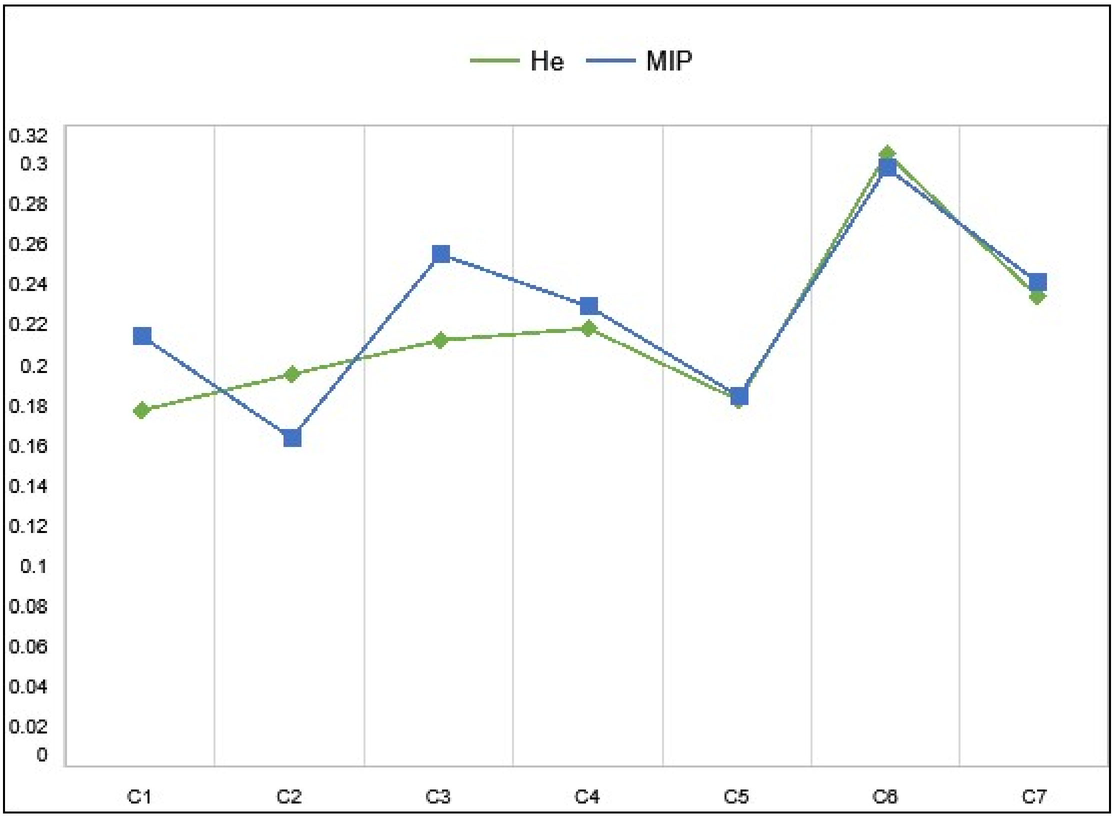

Fig 3: Comparison of Porosity of cuttings by He Porosimeter and MIP