Tikrit University

The College of Petroleum Processes Engineering

Petroleum and Gas Refining Engineering Department

An Introduction to Petroleum Technology

First Class

Lecture (4)

By

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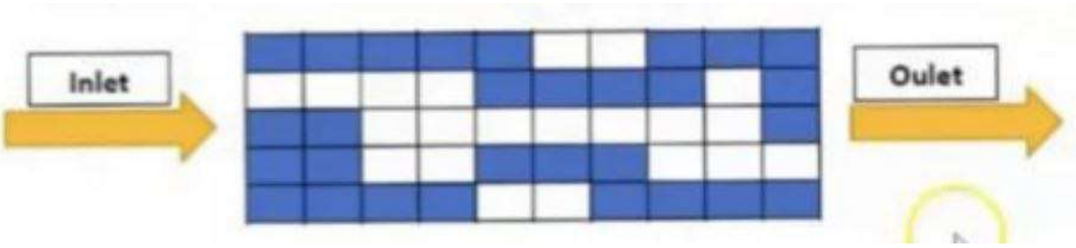
Example (1)

Calculate the effective porosity , total porosity and residual porosity of a 2-dimensional hypothetical porous medium shown below:



Note:

Blue grids represent the grain>

White grids represent the pores.

Answer:

Total volume= 5x10= 50

Connected pores volume= 17

Unconnected pores volume= 4

Total pores volume= **Connected pores volume + Unconnected pores volume**

= 17+4=21

Total porosity (φ_T) = $\frac{Total\ pores\ volume}{Total\ volume} = \frac{VP}{VB} = \frac{21}{50}$ = 0. 42 or 42%

Effective porosity (φ_e) = $\frac{Connected\ pores\ volume}{Total\ volume} = \frac{17}{50}$ = 0.34 or 34%

Residual porosity (φ_r) = $\frac{UnConnected\ pores\ volume}{Total\ volume} = \frac{4}{50}$ = 0.08 or 8%

4-1 Laboratory measurements of porosity:

Several method : involves only determination of two out of three basic parameters (V_p , V_G and V_b)

To measure bulk volume in laboratory, must prevent fluid penetration into the pore sample by:

1- Coated sample with paraffin or a similar substance and immersed in water.
2- Water –saturation sample immersed in water , or saturating the sample with the fluid into which it is to immersed.
3- Using mercury (dry sample immersed in Hg method)

Grain volume: by Melcher –nutting method in which the sample is crushed and its volume measured with a pycnometer.

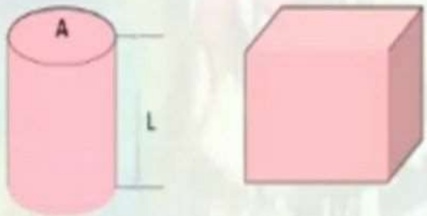
Pore volume: the simplest method of determining pore volume involves directly saturating the core with fluid such as water or oil and using the mass difference method to determine the volume of fluid required to fully saturate the core sample, as shown in equation:

$$Vp = \frac{Wsat. - Wdry}{\rho liq.} \qquad 4\text{-}1$$

Lab. Measurements of porosity

- ***Porosity measurement***
  - V_b, bulk volume directly measured (Irregular & regular sample shapes)

➢ Direct measure, V_b
Common shaped sample (cylinder, or cubic) measured the dimensions and consider bulk volume



❖ To measure V_b in laboratory, must prevent fluid penetration into the pore sample by:
- coating with wax
- saturating the core with same fluid
- using mercury

❖ Example 1.1 – Porosity Calculation

➢ Determination of V_b – Coating Method (A sand stone sample with ρm = 2.67 gm/cc)

- A = mass dry sample in air = 20.0 gm
- B = mass dry sample coated with paraffin = 20.9 gm $Sg_{paraffin}$ = 0.9
- C = mass of coated sample immersed in H_2O at 40ºF = 10 gm (Sg_{water} = 1.0)
- Mass of paraffin = B – A = 20.9 – 20.0 = 0.9 gm
- Volume of paraffin = 0.9/0.9 = 1 cc
- Mass of water displaced = B – C = 20.9 – 10.0 = 10.9 gm
- Vol. of water displaced = mass of water/ρ of water = 10.9/1.0 = 10.9 cc
- Bulk volume = volume of water displaced – volume paraffin
- = 10.9 – 1.0 = 9.9 cc
- Bulk volume of rock = 9.9 cc

❖ Example 1.2 – Porosity Calculation

- From Example 1.1
- Mass of dry sample in air = 20 gm
- Bulk volume of sample = 9.9 cc
- Grain volume of sample = (mass of dry sample in air)/ (sand-grain density)
- = 20/2.67 = 7.5 cc
- Total porosity = $Ø_t$ = [(bulk vol. – grain vol.)/bulk volume] x 100
- = [(9.9 – 7.5)/9.9] x 100 = 24.2 per cent

❖ Grain density of some minerals

Rock	Density (gm/cc)
Sandstone	2.65
Limestone	2.71
Dolomite	2.87
Anhydrite	2.98
Salt	2.17- 2.05
gypsum	2.35
feldspars	2.50-2.67
water	1

Example 1.3

- A clean and dry core sample weighting 425g was 100% saturated with a 1.07 specific gravity brine. The new weight is 453g. The core sample is 12 cm long and 4 cm in diameter. Calculate the porosity of the rock sample.

❖ SOLUTION:

The bulk volume of the core sample is:

Vb = $\pi(r)^2$ (12) = 150.80 cm^3

The pore volume is:

Vp = 1/ų (V_{wet} - V_{dry}) = (453-425)/ 1.07 = 26.17 cm^3

- Then; Porosity of the core is:

ϕ = Vp/Vb =26.17 / 150.8= 0.173 or 17.3%

Example (4)

A core sample wase sent to the laboratory as part of the core analysis. The sample was cleaned and dried,then saturated with water. The saturated core sample was further submerged in water and the apparent weighted in water was measured. The following data obtained from the saturation experiment.

W dry = 110.35 gm

W sat. =135.83 gm

W sub. =20 gm

Determine Vb , Vp and the porosity.

What kind of porosity value was determined from this experiment?

Answer:

Weight of liquid displaced by liquid saturated core sample= Wsat. – Wsub

= 135.83 – 20 = 115.83 gm.

Volume of water displaced = bulk volume of core sample (Archimedes base)

$V_{\text{wat-disp.}}$ **= Vb=** $\frac{Vwat-disp.}{\rho liq}$**=** $\frac{115.83}{1}$**=** 115.83 cm3

Vp = $\frac{Wsat.-Wdry}{\rho liq.}$ **=** $\frac{135.83-110.35}{1}$**=** 25.48 cm3

Porosity (Φ)= $\frac{Vp}{Vb}$**=** $\frac{25.48}{115.83}$**=** 0.22 = 22%

The porosity it calculated is effective porosity because only connected pore space could have been saturated by water.

4-2 Average porosity Example:

- Calculate the arithmetic average and thickness-weighted average from the following measurements:

sample	Thickness, ft	Porosity %
1	1	10
2	1.5	12
3	1	11
4	2	13
5	2.1	14
6	1.1	10

- ***Solution:***
- Arithmetic average:

$$\emptyset = \frac{10 + 12 + 11 + 13 + 14 + 10}{6} = 11.67\%$$

- Thickness – weighted average

$$\emptyset = \frac{(1)(10)+(1.5)(12)+(1)(11)+(2)(13)+(2.1)(14)+(1.1)(10)}{1+1.5+1+2+2.1+1.1} = 12.11\%$$

4-3 Saturation

In most oil formation it is believed that the formation was fully saturated with water prior to the oil migration and trapping in the formation. The less dense hydrocarbons are considered to migrate to positions of hydrostatic and dynamic equilibrium by displacing the initial water. The oil will not displace all the water originally occupied these pores. Thus reservoir rocks normally contain both hydrocarbon and water (frequently referred to as connate water or interstitial water). Saturation is defined as that fraction, or percent, of the pore volume occupied by a particular fluid (oil, gas, or water). This property is expressed mathematically by the following relationship:

$$fluid\ saturation = \frac{total\ volume\ of\ the\ fluid}{pore\ volume}$$

Saturation is a fraction of the pore volume occupied by a particular fluid.

$Vp = Vo + Vg + Vw$ 4-2

$So = \frac{Vo}{Vp}$ 4-3

$Sg = \frac{Vg}{Vp}$ 4-4

$Sw = \frac{Vw}{Vp}$ 4-5

Where: So: oil saturation, Sg: gas saturation, Sw: water saturation

Notes (very important):

1- When the reservoir pressure is less than the bubble point pressure, there will be liberated gas. In the voids of the rocks, there are three phases: gas phase, oil phase, and water phase.

$So+Sw+Sg = 100\%$ 4-6

2- When the reservoir pressure is higher than the bubble point pressure, there is no free gas in the voids of the rocks, so there are only two phases: the oil phase, and the water phase.

$So+Sw= 1$ 4-7

3- The distribution of fluids within the voids of rocks is according to the wettability property. If there is water and oil; the water will be attached to the wall of the granules, and the oil will be in the middle. But if gas is present with water and oil; the water adheres to the wall of the grains, followed by the oil, and the gas is in the middle of the voids of the rock.

4- The distribution of saturations in the reservoir changes from bottom to top; Where the water saturation is greatest at the bottom of the reservoir, then the saturation of the oil in the reservoir increases and the water saturation decreases at the top, and when the gas phase is present, the gas saturation is the largest at the top of the reservoir.

5- There is always water in the reservoir, even if the reservoir is oil, and this water is called:

Connate water saturation (Swc) : It is the water that can not be displaced by production processes.

Or it is the amount of the water cannot be produced .

6- There is also an amount of oil that cannot be removed from the rocks, which is: **Residual oil saturation (Sro)** .

Residual oil saturation (Sor) : It is the lowest value of the oil saturation in the reservoir that cannot be removed from the reservoir rocks (it is the amount of oil inside the reservoir rocks, which cannot be produced no matter how recovery it is).

5-2 Movable oil saturation (So_m)

It is the saturation of the oil that moves and can be removed from the rocks and produced.

$$So_m = 1- (Sor +Swc+Sgc) \qquad 4\text{-}8$$

Where:

Sor: It is the lowest value of the oil saturation in the reservoir that cannot be removed from the reservoir rocks.

Swc: the amount of the water cannot be produced.

Sgc : It is the lowest value of the gas saturation in the reservoir at which the gas begins to move, it is the saturation of the immobile gas. The gas phase remains immobile until its saturation exceeds certain saturation, called critical gas saturation, above which gas begins to move.

Measurement of Saturation

Estimates of reservoir saturation can be obtained from several sources both:

a- Direct methods in the laboratory.

b- Indirect methods by using well logs (Resistivity log) or using MBE or measurement the capillary pressure.

Average Saturation

Proper averaging of saturation data requires that the saturation values be weighted by both the interval thickness hi and interval porosity f. The average saturation of each reservoir fluid is calculated from the following equations:

$$S_o = \frac{\sum_{i=1}^{n} \phi_i \, h_i \, S_{oi}}{\sum_{i=1}^{n} \phi_i \, h_i}$$

$$S_w = \frac{\sum_{i=1}^{n} \phi_i \, h_i \, S_{wi}}{\sum_{i=1}^{n} \phi_i \, h_i}$$

$$S_g = \frac{\sum_{i=1}^{n} \phi_i \, h_i \, S_{gi}}{\sum_{i=1}^{n} \phi_i \, h_i}$$